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MIGRATION OF ADULT CHINOOK SALMON AND STEELHEAD PAST DAMS AND THROUGH RESERVOIRS IN THE LOWER SNAKE RIVER AND INTO TRIBUTARIES - 1991

Annual Report for 1991

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Portland, OR

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Acknowledgments

Several people and agencies contributed to the success attained during the first year of the study of adult salmon and steelhead passage in the Snake River basin. The Corps of Engineers provided the major part of the funding, with additional funds from Idaho Department of Fish and Game and Oregon Department of Fish and Wildlife. Sarah Wik initially, and then Teri Barila of the Corps' Walla Walla District were project officers. Jim Athearn of the Corps, Ron Boyce of ODFW, and Steve Pettit of IDFG played important roles in launching the project. Jed Volkman, Chris LeSage, Robert Keith, Ty Nesheim, Ann Storer, Shawna Wood, and others helped with the fish trapping, tagging, data processing, and report preparation. Idaho, Oregon, and Washington personnel monitoring the fisheries and spawning grounds aided in the recovery of tagged fish. Hatchery personnel in all three states aided by collecting tags and transmitters from fish entering the various hatcheries. Fish counters at the four dams kept counts of the four groups of spaghetti-loop tagged fish released for the zero-flow study.

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Abstract

A study of the upstream migration of adult spring and summer chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* past the four lower Snake River dams, through the reservoirs, and into the tributaries of the Snake River drainage was initiated in 1991. The objectives were to evaluate the effect of spill, powerhouse operation, and flows on the rates of passage at the dams, migration through the reservoirs, fishway entrances used, fallback at the dams, and movements into the tributaries upstream from the reservoirs.

Transmitters were placed in 531 spring and summer chinook salmon and 728 steelhead and the fish were then released near Ice Harbor Dam and monitored as they continued their migration to assess migration rates and success. Spagetti-loop and metal jaw tags were placed on 1,976 steelhead released near Ice Harbor Dam during four periods of normal or zero flow at night from the three upper dams to assess the effect of reduced flow at night on migration. Electronic tunnels were installed in or near each fishway entrance at the two upper dams to assess use and fallout. A section of fence was installed near the north powerhouse entrances at the two upper dams to determine if fallout would be reduced from that observed in earlier years.

Success of passage for the spring and summer chinook salmon from the Ice Harbor Dam tailrace to the forebay at Lower Granite Dam was an estimated 87% in 1991, based on fish recorded at the tailrace receiver at Ice Harbor Dam and those recaptured at the Lower Granite adult trap. Seventy-five percent of the salmon released, that attempted to return back up the Snake River, successfully passed the four dams and reservoirs. About 55% of the fish with transmitters successfully migrated to natal streams or hatcheries, but there was evidence that several fish destined for hatcheries did not enter the hatcheries.

The distribution of spring versus summer chinook salmon in the Snake River basin varied by tributary. Fish entering most of the hatcheries included both spring and summer chinook salmon, based on time of passage at Ice Harbor Dam.

The time required for chinook salmon to pass the four Snake River dams ranged from 7.9 d at Ice Harbor Dam to 1.8 d at Little Goose Dam in

1991. Migration through the reservoirs was rapid at about 55 km/d (1.4 to 1.8 d per reservoir). The rate of migration in the free flowing rivers was slower than in the reservoirs at 15 to 31 km/d.

The distribution of spring and summer chinook salmon with transmitters throughout the Snake River basin in 1991 was 25% into the Clearwater River, 9% into the Grande Ronde, 4% into the Imnaha, and 62% into the Salmon River.

Of the 710 tagged (all types of tags) steelhead recaptured in the fisheries of the three states and reported to us by 12 May 1992, 21 were caught from the Columbia River, 10 from the Walla Walla River, 226 from the Snake River from the mouth to Lewiston, 11 from the Tucannon River, 131 from the Clearwater River, 115 from the Snake River upstream from Lewiston, 45 from the Grande Ronde River, 2 from the Imnaha River, and 149 from the Salmon River. So far, 103 tagged steelhead had been reported at hatcheries, with 50 at Dworshak being the largest number.

Two types of data have been summarized for the zero-flow test, counts of spaghetti-loop tagged steelhead at each of the dams, and recaptures of the fish at the Lower Granite adult trap. The last group of steelhead released in late October and early November during normal flow at night obviously migrated slower than the three earlier groups. Differences in migration rate and percentage counted between the first three groups were less obvious, but some were statistically significant. River temperature was a factor in the tests, and additional testing will be required to determine the biological significance of differences observed.

Fishway entrance use by salmon and steelhead varied by season and dam, with some change related to powerhouse discharges. At Little Goose Dam the south shore entrances were the most used, while at Lower Granite Dam the north shore entrance was most used. North powerhouse entrances 1 and 2 at both dams were little used as entrances, but many fish exited the fishway via those portals. Floating orifice entrances were little used and there was little fallout at those openings. Use of north powerhouse entrance 3 was highest in the fall at both dams. The "fallout fence" did not prevent or reduce fallout of salmon or steelhead at north powerhouse entrances at both dams.

Introduction

Adult spring and summer chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* migrating to their natal streams in the Snake River basin must pass over eight dams and through as many reservoirs, four of which are in the lower Snake River. Losses of adults and delays in migration at each hydroelectric project must be kept to a minimum if we hope to succeed in maintaining the native runs of fish and achieve the Northwest Power Planning Council (NPPC) goal of doubling the abundance of fish in the future.

These studies address concerns of the Corps of Engineers (Corps) and section 603 of the NPPC's 1987 Columbia River Basin Fish and Wildlife Program, and the need to conduct studies to determine the effects of reduced and instantaneous flows on adult fish. Also included in the Program was the need to study flows at fishway entrances to determine the best flows and operation conditions.

The study was developed in consultation with Corps personnel, and in response to the high priority assigned to adult passage research in the Snake River by the Fish Research Needs and Priorities subcommittee of the Corps of Engineers' Fish Passage Development and Evaluation Program. The NPPC outlined adult passage problems in 1988 and urged that research be undertaken. In 1989, the Fish Passage Center recommended as top priority for the Corps' Walla Walla District, a study to verify which spill patterns at the Snake River dams will result in the least fallback.

Research has been conducted in the past by personnel of the Corps, Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU), Oregon Department of Fish and Wildlife (ODFW), and National Marine Fisheries Service (NMFS) to evaluate passage rates, entrance and fallout in the passage facilities, fallback over the dams, spill and tailrace flow patterns, and migration rates with reduced nighttime flows at the Snake River dams. Facilities and operating procedures were modified as a result of earlier studies, and studies are needed to determine if the changes will result in the desired improvements. The studies by Turner et al. (1983, 1984) were conducted during only a part of the migration season and with an incomplete range of flow conditions, and they recommended further study. Some of the studies were conducted before the full complement of turbines had been installed in the Snake River dams.

Additional studies were needed to better define: (1) the effects of an extended period of zero flows at night on the passage of adult fish over the dams and through the reservoirs, (2) the effect of spill configuration on the entry of fish into the fishway and the passage rate, (3) the rate of fallout from fishway entrances with a special fishway fence in the powerhouse collection channel, (4) the rate of fallback over the dams with various flow

conditions, and (5) the distribution, migration rates, and survival of fish after they leave Lower Granite Dam.

Objectives for the studies conducted in 1991 were as follows:

1. Determine the effects of zero flow at night on migration rates, and on the proportion of adult steelhead passing each dam, entering the fisheries, and returning to hatcheries.
2. Determine the effects of quantity of spill and the patterns of spill on the rate of passage, and fishway entrance use by adult spring and summer chinook salmon at the four lower Snake River dams.
3. Evaluate the effectiveness of a fence installed in the fishway at Little Goose and Lower Granite dams for reducing the rate of fallout by adult salmon and steelhead at the powerhouse fishway entrances.
4. Assess the fishway entrance preferences of adult salmon and steelhead at Lower Granite and Little Goose dams under various conditions of flow, spill, and powerhouse operation.
5. Assess the rate of adult salmon and steelhead migration up the lower Snake River under various, normally occurring conditions of flow, spill, powerhouse operation, and season of the year.
6. Assess the rate and route of fallback of adult salmon and steelhead over or through the lower Snake River dams under various conditions of spill, flow, powerhouse operation, and season of the year.
7. Determine the effects of pile driving near Lower Granite dam on the upstream migration of steelhead in summer.
8. Determine the timing of migration, migration rates, distribution of fish, and survival rates of salmon and steelhead after they leave Lower Granite Dam.

The area of study extended from McNary to Priest Rapids dams on the Columbia River, the Snake River from the mouth of the river upstream to Hells Canyon Dam, all the major Snake River tributaries, and at hatcheries where tagged fish were recovered. The work was divided into two major segments, tracking of fish outfitted with radio transmitters past the dams and into the tributaries by ICFWRU personnel, and monitoring of fishway entrance use at two dams with electronic tunnels by ODFW personnel.

EVALUATION OF MIGRATION RATES AND PASSAGE OF ADULT CHINOOK SALMON AND STEELHEAD IN THE SNAKE RIVER AND TRIBUTARIES USING RADIO TELEMETRY AND FISH TAGGING - 1991

by

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Introduction

Studies to assess migration rates and passage success of adult spring and summer chinook salmon and steelhead at the lower Snake River dams and into the tributaries were conducted in 1991 using fish captured at Ice Harbor Dam (Figure 1) and outfitted with radio transmitters or spaghetti-loop tags. Radio transmitters were placed in 531 spring and summer chinook salmon and 728 steelhead to monitor their passage at the dams and into the tributaries, to assess rates of migration, time to pass each dam, the number that fell back at each dam, distribution of fish into the tributaries, and the proportion that completed migrations to spawning grounds or hatcheries. Spaghetti-loop tags were used on 1,976 steelhead during the fall to evaluate the effects of zero flow at night on migration rates and passage success.

The influence of spill on migration rates, fishway entrance preferences, and fallback was not fully evaluated in 1991 because of the low volume of the spring runoff and lack of spill at Lower Granite and Little Goose dams. The effect of spills at Lower Monumental and Ice Harbor dams for juveniles during the spring will be analyzed using fish with transmitters.

The results of the radio telemetry studies in 1991 have been divided into three segments: migration rates and passage success of chinook salmon, migration rates and passage success of steelhead, and the effects of zero flow at night on steelhead migrations. The report on chinook salmon movements is mostly complete as most of the records of movements for chinook salmon were obtained from April through October

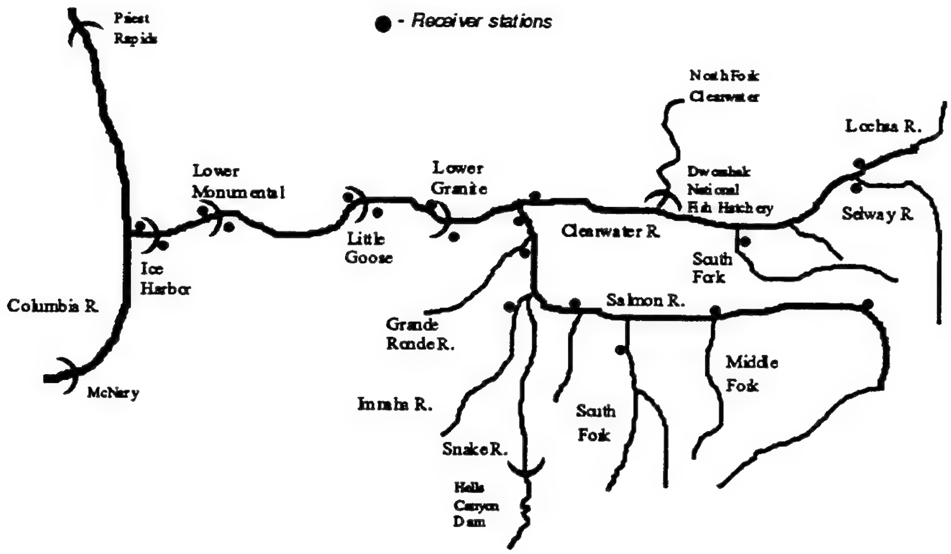

Figure 1. Map of the Snake River Drainage and dams. Black dots represent the location of receiver stations throughout the drainage during 1991.

1991, but we received some reports of recaptures as late as March 1992. The reports on steelhead movements will be incomplete because fish tagged and released in the summer and fall of 1991 were still alive and migrating when this report was prepared. Complete information on the steelhead movements during 1991 and 1992 will not be available until the spring 1993 report.

Chinook Salmon - Migration Rates and Passage Success

Methods

The upstream migration of adult chinook salmon was monitored by releasing fish with radio transmitters at Hood Park (16.3 km downstream from Ice Harbor Dam near the mouth of the Snake River) and monitoring their migration at each of the dams and into the major tributaries using fixed-location receivers, mobile tracking receivers, and recapture of fish at traps, hatcheries, and recoveries from spawning grounds. The fixed-location receivers and associated antennas were installed at the dams and mouths of major tributaries in the spring of 1991 before the expected passage of fish with radio transmitters.

Fixed-location receivers were installed 0.5 to 2.0 km downstream from each of the four lower Snake River dams with two antennas at each site to determine when fish entered the tailrace area of each dam. Fixed-location receivers were also installed at the top of

each dam (with up to eight antennas each) to monitor when fish left the top of the fishway, and their movements in the forebay. At Little Goose and Lower Granite dams, receivers were also located on the powerhouse deck with antennas (mostly underwater) at various fishway entrances and in the fishway collection channel (Figure 2) to determine when fish had entered the fishway. Receivers with underwater antennas were also placed at the sorter of the downstream migrant collection facilities of the two upper dams to monitor fish falling back through the turbine intakes and diverted into the collection facilities.

Three pickup trucks were outfitted with 4-element yagi antennas that could be rotated from within the cab to track the fish with transmitters in areas not covered by the fixed-location receivers. A boat was also set up for mobile tracking. Once the fish began to move upstream beyond the Lower Granite pool and into the tributaries, mobile tracking was initiated on a schedule that called for checking streams with road access every two weeks or less. Mobile tracking in the tributaries continued into September until the salmon had spawned and died.

During the 1991 spring and summer chinook salmon runs, 531 fish were outfitted and released with radio transmitters at Hood Park. Spring chinook salmon began passing over Ice Harbor Dam in early April. We began capturing fish and outfitting them with transmitters on 20 April and released the last fish on 4 July 1991 (Figure 3). We interrupted the capture and releasing of fish with transmitters in late May because we had used 306 of the transmitters (61%) scheduled for use on spring and summer chinook salmon. On 1 June we began releasing fish with transmitters again and continued until 4 July.

Of the 531 fish released with transmitters, 305 (57%) were released in April and May, and 226 (43%) were released in June and July (Figure 3). We ended up releasing 31 more fish with transmitters than planned because we reused transmitters from fish recaptured at hatcheries that were returned to us before the 4 July cessation of tagging. Based on the counts compiled by the Fish Passage Center, 11,288 spring chinook and 5,861 summer chinook salmon were counted at Ice Harbor Dam in 1991, with spring chinook salmon making up 66% of the total. If the fish we released in April and May were mostly spring chinook salmon and those in June and July mostly summer chinook salmon, then we did not tag fish in those two runs in exact proportion to their abundance. There was a nadir in chinook salmon counts at Ice Harbor Dam in late May that may have been the normal decline between the spring and summer runs of fish, or caused by the block of turbid water that moved through the system at that time (Figure 3).

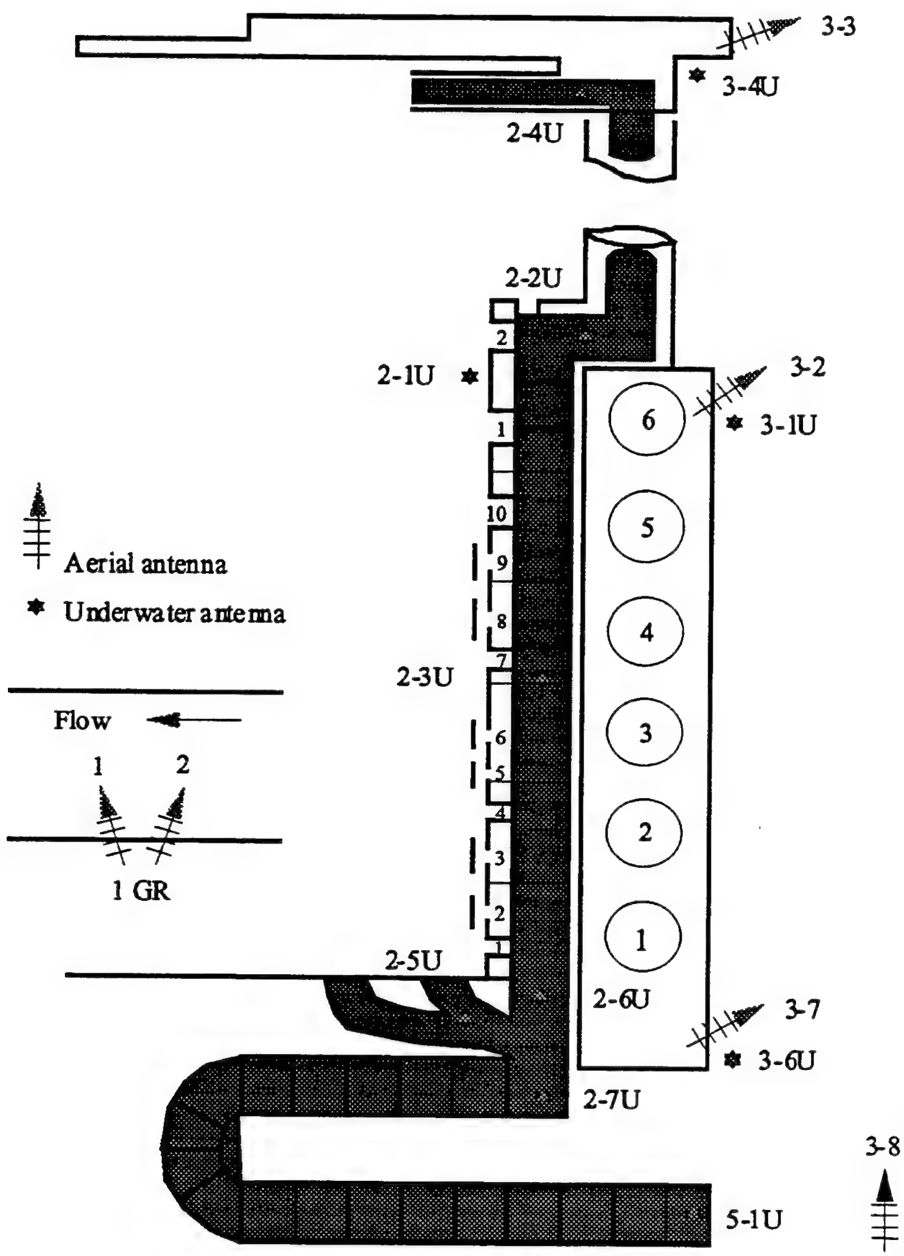

Figure 2. Drawing of Snake River dam with locations of antennas in 1991. The first number of the receiver code is the receiver number, the second number is the antenna, and the letter U designates underwater antenna.

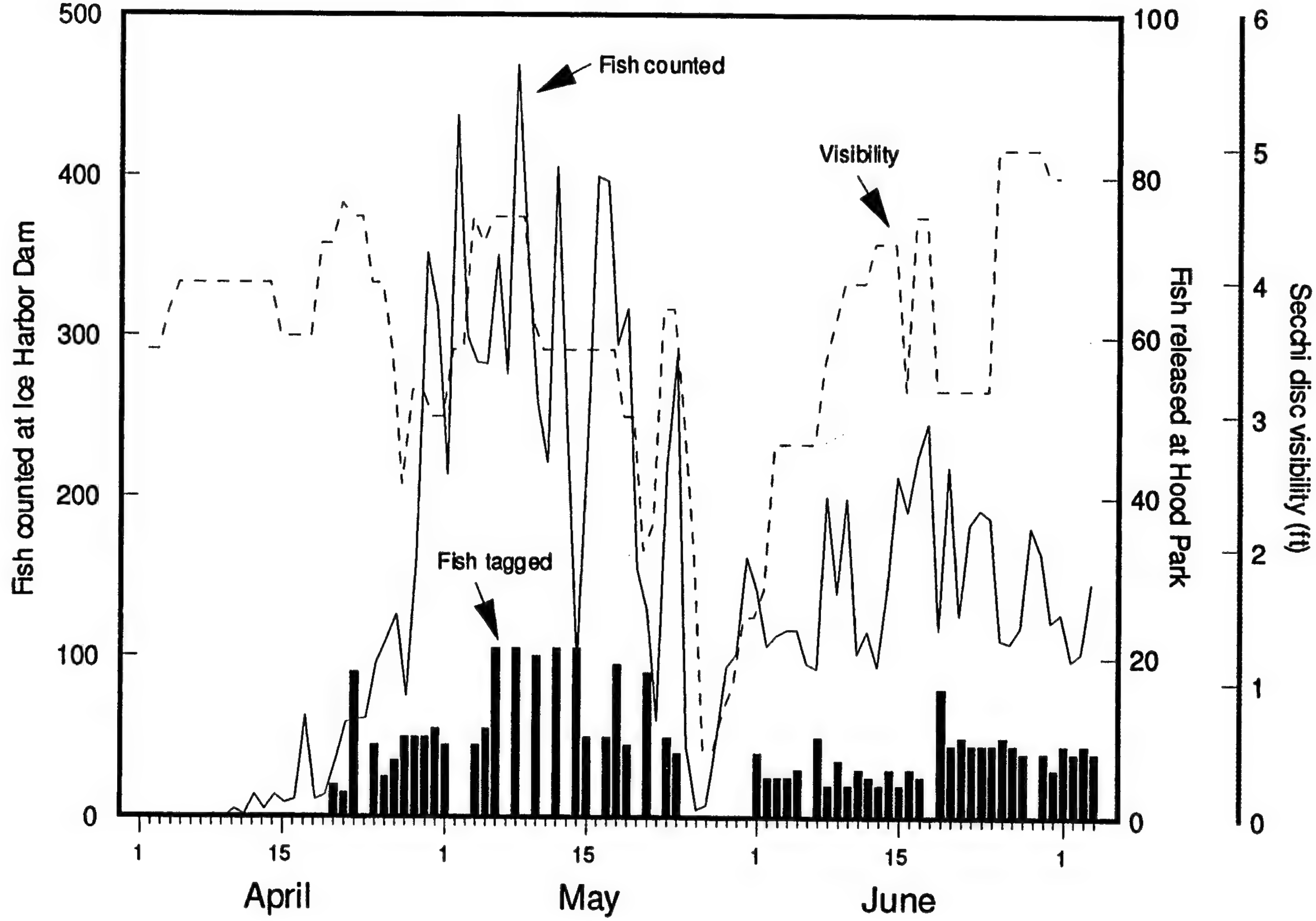

Figure 3. Comparison of chinook salmon counted at Ice Harbor Dam, chinook salmon tagged and released at Hood Park, and secchi disc visibility at Ice Harbor Dam, April 1 to July 4 1991.

The radio transmitters and receivers used in 1991 were manufactured by Lotek Engineering Inc., of Aurora, Canada and yagi antennas by Cushcraft. The transmitters (95 mm X 18 mm) emitted a digitally coded signal every 5 seconds that could be interpreted by the receiver as a unique numeric code that was recorded in a data bank along with the channel (frequency of the transmitter), relative power of the signal, antenna receiving the signal, date, and time. There were eight data banks in the receiver that could store a total of about 64,000 records. The receiver data banks were downloaded as files in a portable computer every 1 to 4 weeks depending on the location and fish activity at the site. Receiver reliability was high in general, with only a few gaps in the data resulting from loss of electric or battery power, or from receiver malfunction (Figure 4).

The fish outfitted with transmitters (inserted into the stomach through the mouth) in 1991 were the larger fish in the run (all were longer that 70 cm fork length, Figure 5) because of the size of the transmitter. A large proportion of the fish outfitted with transmitters had spent three years at sea (termed three-ocean fish). The proportion of three-ocean fish varies from stock to stock, and thus, some stocks may not have been equally represented in the sample of fish outfitted with transmitters in 1991. All of the hatcheries with predominantly spring chinook salmon (Rapid River, Lookingglass, Kooskia, and Dworshak) had more two-ocean than three-ocean fish in 1991 (Figure 5). In the hatcheries with more summer chinook salmon (South Fork/McCall, Pahsimeroi, and Sawtooth) the larger fish made up a larger part of the fish returning in 1991. To get a truly random sample of fish that had spent two or three years at sea, we need to include all fish longer than about 60 cm. Transmitters that will be used in 1992 have been reduced in size (80 mm X 16 mm) without a loss of transmitting power and life and will fit in fish down to 58 cm.

In addition to the radio transmitter, all fish released were tagged with a numbered aluminum band on the lower jaw, and a coded-wire tag inserted in the muscle near the dorsal fin. The jaw tag was used as a backup means of identifying fish released with transmitters, and the coded-wire tag was used to trip the detector at the adult trap in the ladder at Lower Granite Dam.

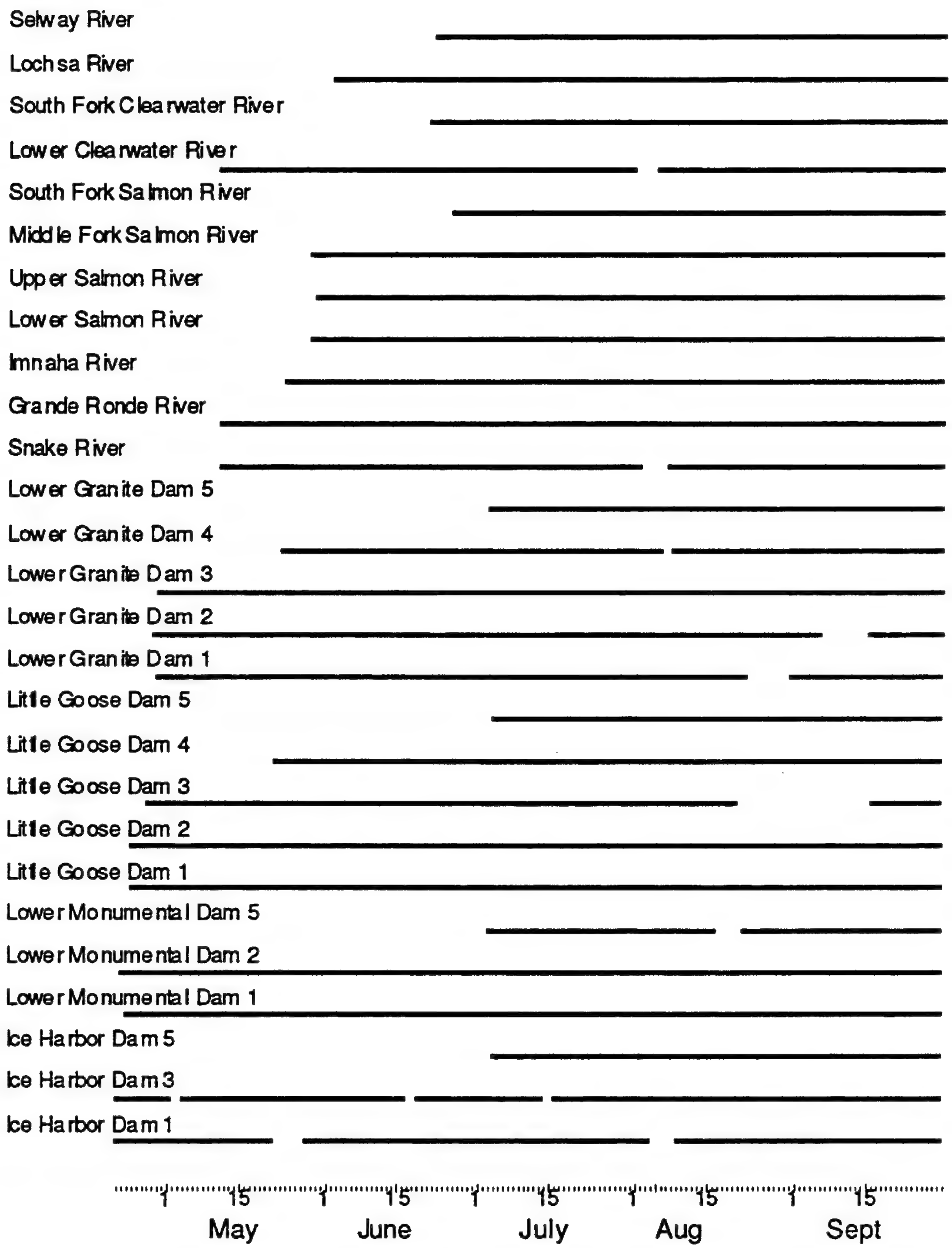

Figure 4. Diagram to illustrate periods of operation of fixed-location receivers at dams and tributaries in the Snake River basin in 1991. Breaks in the lines represent periods of non operation.

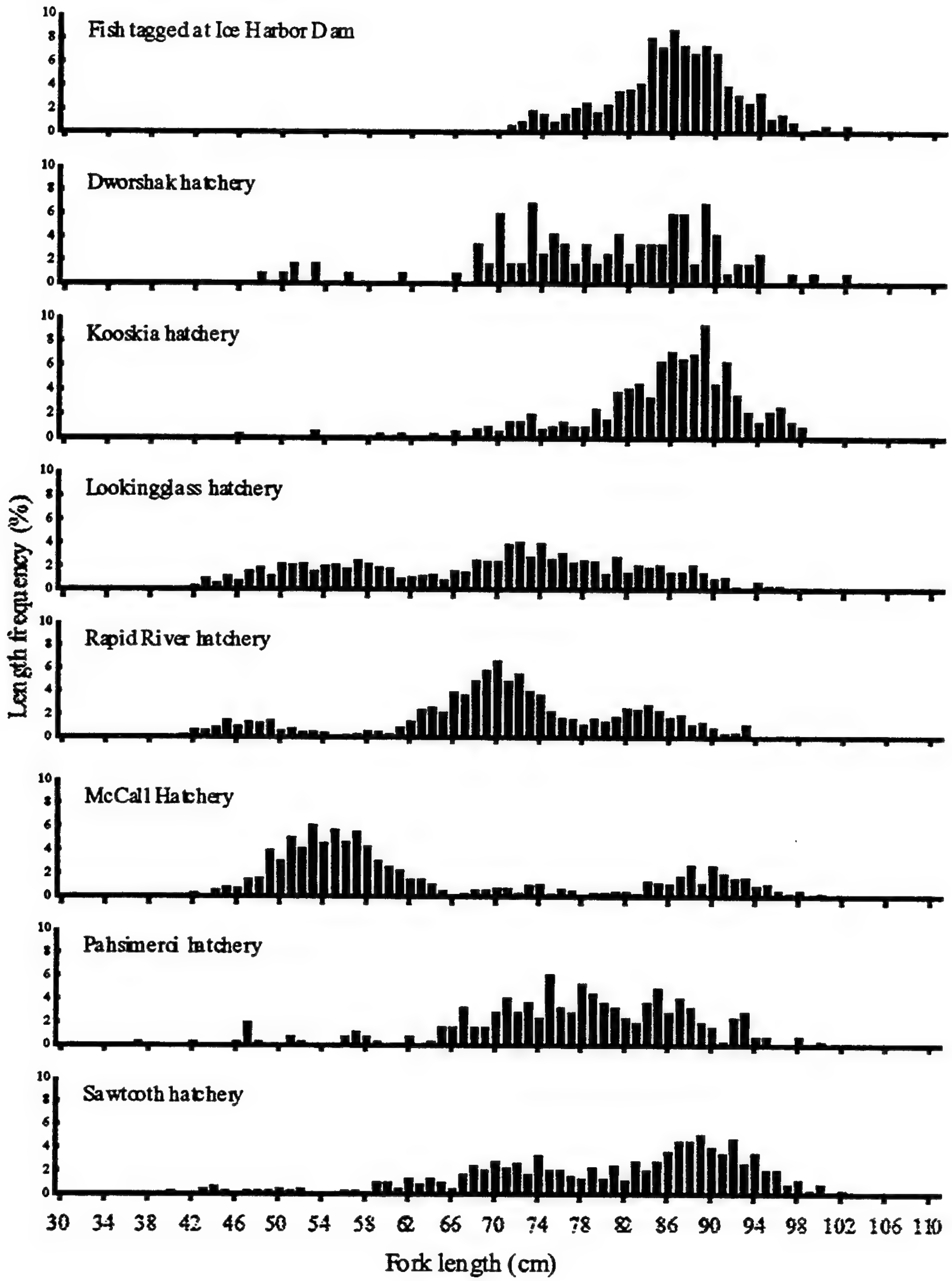

Figure 5. Length frequency distribution of spring and summer chinook salmon outfitted with transmitters at Ice Harbor dam in 1991, and salmon returning to the various hatcheries in the Snake River basin.

The usual trapping and tagging operation started at about 6 am each morning by lowering screens into the V-weir opening in the top pool of the south ladder at Ice Harbor Dam to force fish to go through the trap box where they could be observed and selected or allowed to continue their migration. Fish that were suitable for tagging and a transmitter were diverted from the trap box into an adjacent holding pen until the number needed had been collected. The holding pen was then lifted by crane to the top roadway across the dam and the fish deposited in an insulated tank on a truck. The lower 45 cm of the holding pen was constructed of sheetmetal to retain water when lifted from the ladder so the fish were always in water. A canvas sleeve attached to a hole in the bottom of the holding pen was used to transfer the fish from pen to tank. Water in the tank was obtained from the forebay at the dam and anesthetic (MS222) was added (one-half the normal dose) before the fish were put in the tank.

The fish were then taken downstream to Hood Park where they were taken from the tank one at a time via a slick-sided bag and placed into a large plastic tub containing a full dose of anesthetic. Each fish was examined for marks, measured, jaw and coded wire tagged, outfitted with a transmitter, and then placed in a pen in the river to recover. If the tagging was completed by midday, the fish were kept in the recovery pen until evening and then released. When tagging was not completed until evening, the fish were held in the recovery pen overnite. The 6 to 15 hr holding period in the recovery pen was primarily to check for transmitter retention immediately after tagging. After releasing the fish, the pen was checked for transmitters that had been regurgitated by fish while in the recovery pen. Transmitters found in the pen were reused in another fish and the records changed to indicate which fish had regurgitated a transmitter.

The migrations of fish with transmitters and jaw tags were recorded in numerous ways starting with release at Hood Park, recording of passage on the fixed-location receivers at the dams and at mouths of the major tributaries, sitings by the mobile trackers, recaptures at the Lower Granite adult trap and at weirs and hatcheries throughout the basin, and recoveries of spawned fish in the tributary spawning areas. Information on some fish was provided by people operating traps at Priest Rapids Dam on the Columbia River, at Three-Mile Dam on the Umatilla River, and by people finding fish or transmitters along the river banks. Each record of a siting or recapture was added to a database and used to decipher the movements of each individual fish (Figure 6).

Results

Passage success Of the 531 spring and summer chinook salmon released at Hood Park with transmitters in 1991, 501 were recorded as entering the tailrace at Ice Harbor Dam, 435 at Lower Monumental Dam, 391 at Little Goose Dam, and 361 at the Lower Granite Dam tailrace (Figure 7). In addition, 370 of the fish were recaptured at the adult trap in the Lower Granite ladder. The above numbers provide minimum survival rates because none of the receivers located downstream from each dam or collections at the Lower Granite trap were 100% efficient. If fish swam past a receiver in the deepest part of the channel it might not get recorded (range limited at water depths greater than 12 m), and there were brief periods when each receiver was out of operation for service or a malfunction. A fish could get by the Lower Granite trap if the detector was not activated.

In 1991, 65 chinook salmon that had been released with transmitters at Hood Park passed over Lower Granite Dam without being caught and recorded at the adult trap. The 65 fish were recorded at receivers or recaptured in traps upstream from Lower Granite Dam. The minimum number of fish outfitted with transmitters that passed over Lower Granite Dam was equal to 435, the 65 untrapped fish plus the 370 that were caught in the Lower Granite trap. Survival of the 501 fish with transmitters that returned to the base of Ice Harbor Dam after release and then proceeded up the Snake River was an estimated 87% (435/501) to the Lower Granite Dam forebay based on fish recaptured at the Lower Granite adult trap.

Fish distributions were also analyzed on the basis of last sitings of fish while mobile tracking, recordings at receivers, recaptures at weirs or hatcheries, and recoveries on spawning grounds or along the rivers. Of the 531 fished released at Hood Park, 7 were never located after release, 16 migrated downstream out of the Snake River into the Columbia River, and 12 were located in the Snake River downstream from Ice Harbor Dam one or more times, but that was the last siting (Table 1). Based on preliminary analysis of the migration records, at least 3% of the salmon tagged did not stay in the Snake River, and another 3.6% either died in the Snake River downstream from Ice Harbor Dam or moved downstream into the Columbia River where they died or migrated into other streams undetected. The combined numbers of fish leaving the Snake River or dying before proceeding up the Snake River (35 fish, 6.6% of those released) may not be unusual for a major confluence of two rivers, but we do not know if the rate is higher than usual because of our trapping and tagging of the fish at Ice Harbor Dam.

Processing of Radio Track Data

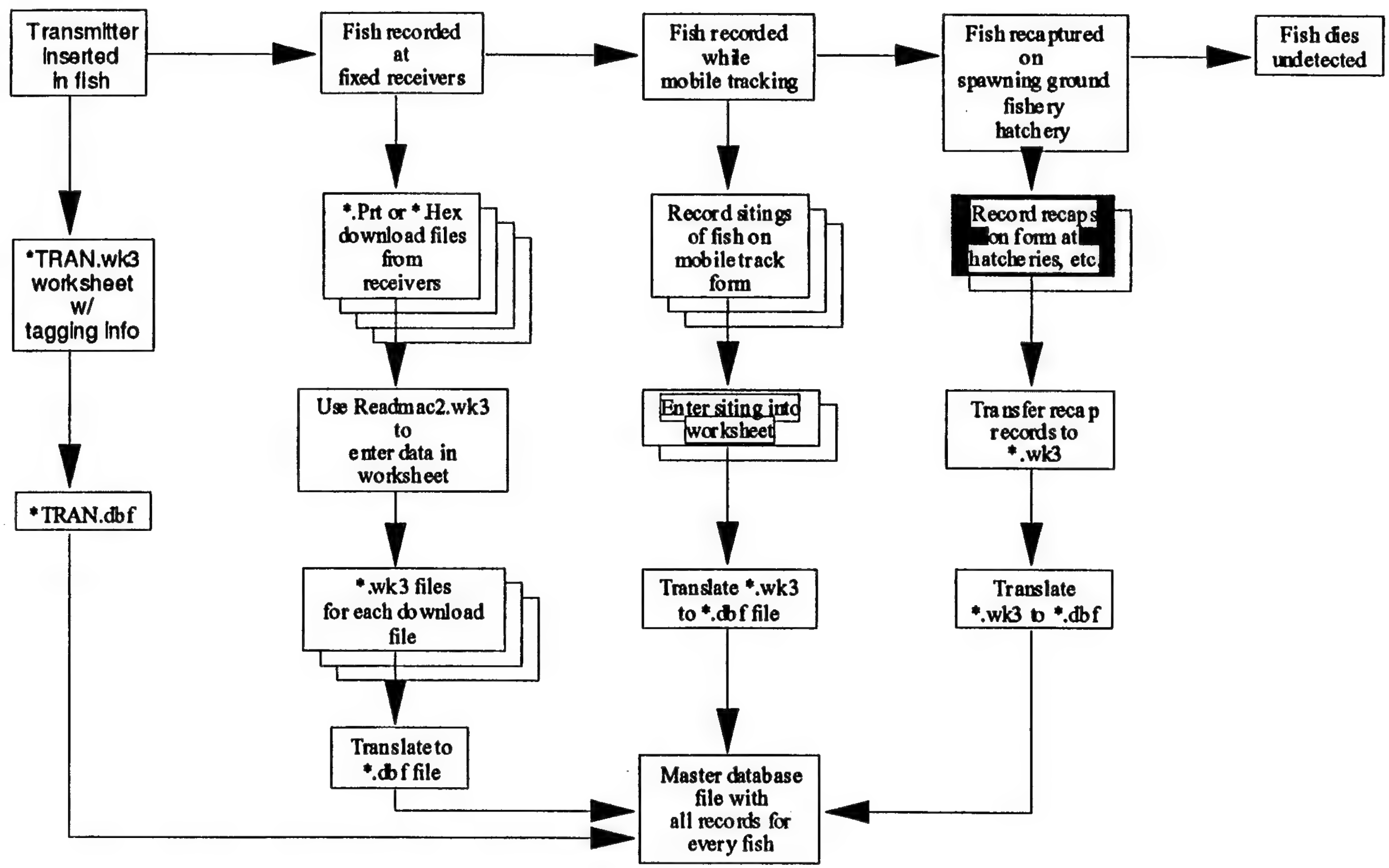

Figure 6. Diagram illustrating the steps taken to process the different sources of radio tracking data (e.g., fixed-location receivers, mobile tracking, etc.) for inclusion in a master database file.

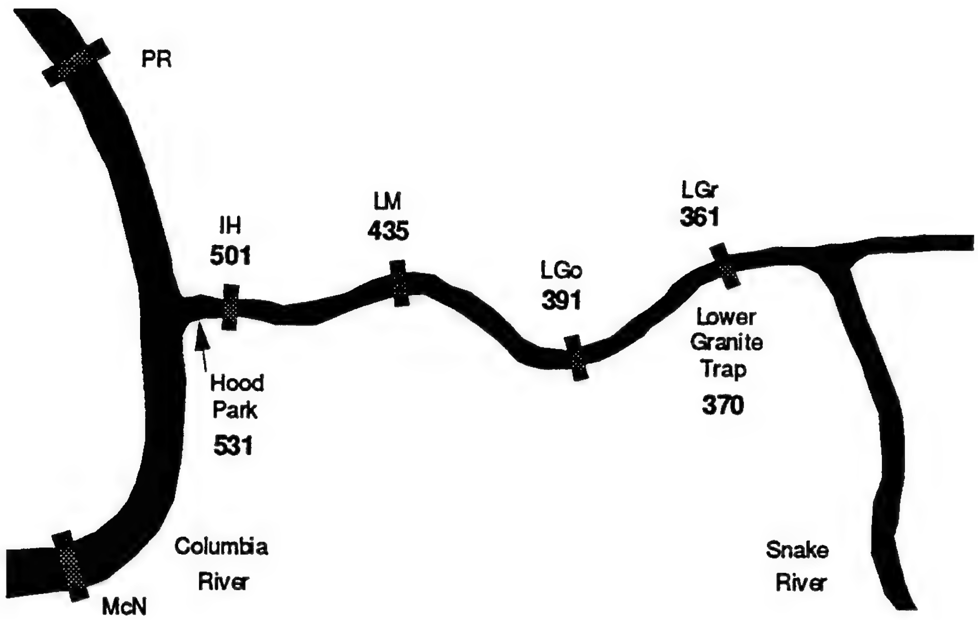

Figure 7. Map of the lower Snake River with the number of spring and summer chinook salmon with transmitters released at Hood Park and those that were subsequently recorded by receivers downstream from each of the four Snake River dams or captured at the Lower Granite adult trap in 1991.

The Ice Harbor Dam and pool were the last places we located 35 (6.6%) of the fish released with transmitters (Table 1). Those fish together with last sitings of 12 fish (2.3%) at Lower Monumental Dam or pool and 20 fish (3.8%) at Little Goose Dam and pool add up to 67 fish (12.6%) of those released that were not located again upstream from the upper end of the Little Goose pool. The 12.6% rate of fish that did not get beyond the Little Goose pool was similar to the "loss" rate between Ice Harbor and Lower Granite Dam calculated from recaptures in the adult trap at Lower Granite Dam, and from regular fish counts at the dams.

Lower Granite Dam and pool were the last places that 53 of the fish were located (Table 1). Those 53 fish plus the 67 fish last located at the other three dams and reservoirs made a total of 120 fish out of the 531 released (22.6%, or 24% of the fish that returned to Ice Harbor Dam) that we could not locate upstream from the Lower Granite pool. A few of those fish may have moved up beyond the Lower Granite pool, but were undetected by fixed-location receivers or mobile trackers. Fish that regurgitated transmitters in the Lower Granite pool, but were recaptured at hatcheries or fish weirs were identified if they still had the jaw tag. Those that migrated into tributaries where they were

Table 1. Location of recapture or last siting of spring and summer chinook salmon outfitted with transmitters and released downstream from Ice Harbor Dam in 1991. Last sitings were at fixed location receivers or by mobile trackers. Recaptures were at hatcheries, fish weirs, during spawning ground surveys, and by people who found fish along the rivers.

Location-description		Number of fish	Percent of fish
Hood Park release site		7	1.32
Columbia River			
Downstream from the Snake River		3	0.56
Deschutes River		1	0.19
Umatilla River		1	0.19
Upstream from the Snake River		8	1.51
Over Priest Rapids Dam		3	0.56
	Subtotal	16	3.01
In the lower Snake River			
Hood Park to Ice Harbor Dam		12	2.26
Ice Harbor Dam and pool		35	6.59
Lower Monumental Dam and pool		12	2.26
Little Goose Dam and pool		20	3.77
Lower Granite Dam and pool		53	9.98
	Subtotal	132	24.86
Clearwater River drainage			
Clearwater River			
Receiver site		13	2.45
Mouth to North Fork		20	3.77
North Fork to Selway River		18	3.39
Lolo Creek		1	0.19
South Fork		5	0.94
Kooskia National Fish Hatchery			
20 3.77			
Selway River		8	1.51
Lochsa River		7	1.32
	Subtotal	92	17.33
Snake River - Lewiston to Hells Canyon Dam		12	2.26
Grande Ronde River drainage			
Receiver site		14	2.64
Grande Ronde river		2	0.38
Weneha River		1	0.19
Wallowa River		3	0.56
Big Canyon Creek		1	0.19
Lostine River		1	0.19
Lookingglass Fish Hatchery		11	2.07
	Subtotal	33	6.21

Table 1. continued.

Location-description		Number of fish	Percent of fish
Imnaha River drainage			
Receiver site		3	0.56
Imnaha River		5	0.94
Imnaha River weir		8	1.51
	Subtotal	16	3.01
Salmon River drainage			
Lower Salmon River - mouth to Riggins		26	4.90
Little Salmon River		11	2.07
Rapid River		10	1.88
Rapid River Fish Hatchery		33	6.21
Middle Salmon River - Riggins to North Fork		7	1.32
South Fork Salmon River			
Receiver site		3	0.56
South Fork		31	5.84
Secesh River		2	0.38
Johnson Creek		2	0.38
South Fork weir		14	2.64
Chamberlain Creek		2	0.38
Middle Fork Salmon River			
Middle Fork		16	3.01
Big Creek		3	0.56
Loon Creek		1	0.19
Sulphur Creek		2	0.38
Bear Valley Creek		4	0.75
Elk Creek		1	0.19
Marsh Creek		2	0.38
Upper Salmon River - upstream from North Fork			
Salmon River		22	4.14
Lemhi River		6	1.13
Hat Creek		1	0.19
Pahsimeroi Fish Hatchery		4	0.75
East Fork Salmon River		6	1.13
Sawtooth Fish Hatchery weir		14	2.64
	Subtotal	223	42.00
	Grand total	531	100.00

unlikely to be found by spawning ground survey crews would not have been detected. When the 12 fish that were last recorded between Hood Park and Ice Harbor Dam are included, a total of 132 fish, nearly 25% of the fish likely to go up the Snake River, did not succeed in migrating beyond the lower Snake River dams and reservoirs (Table 1). This estimate is a maximum estimate because a few fish may not have been detected in rivers and streams upstream from the Lower Granite pool. In addition, the trapping and tagging of the fish may have increased the loss rate, however, the similarity of passage rates from Ice Harbor to Lower Granite Dam based on tagged fish in this study, versus regular dam counts is evidence that tagging effects may have been small. The fraction of the "loss" that can be ascribed to the dams versus natural causes is unknown.

Upstream from the reservoirs, salmon enter the Clearwater River or continue up the Snake River. In 1991, the Clearwater River and its tributaries were the last locations for 92 (17.3%) of the fish released at Hood Park (Table 1). Twenty of the fish entered Kooskia National Fish Hatchery, and 21 entered the other major tributaries (Lolo Creek, South Fork, Selway, and Lochsa rivers). That left 51 fish that were last located in the Clearwater River from the mouth up to the Selway River. Thirteen of those fish were recorded at the fixed-location receiver near the mouth of the river and not located again. The remainder of the fish were spread along the length of the river with a concentration near Dworshak National Fish Hatchery (mouth of the North Fork, Figure 8) and many of the fish were located repeatedly during July, August, and September. At first we thought, most if not, all of the fish would enter Dworshak and Kooskia hatcheries, but they did not, and the transmitters were still present in September, October, and January after the fish had died. None of the fish that were supposed to be carrying the transmitters located in the lower Clearwater River were recovered at any hatchery (would have been identified by jaw tag), thus we believe the fish died in the river. We do not know if they tried to spawn in the Clearwater River. The lack of returns of fish with transmitters to Dworshak Hatchery, and the small number returning to the hatchery leads us to suspect that most of the fish were destined for the hatchery, but for some reason failed to enter. If the 38 fish that we believe died in the Clearwater River did not spawn successfully, more than half the fish that entered and stayed in the Clearwater River drainage may have died before spawning. Only one fish entered the Clearwater River as far as the fixed-location receiver (about 7.5 km up from mouth) was recorded and then moved back down into the Snake River.

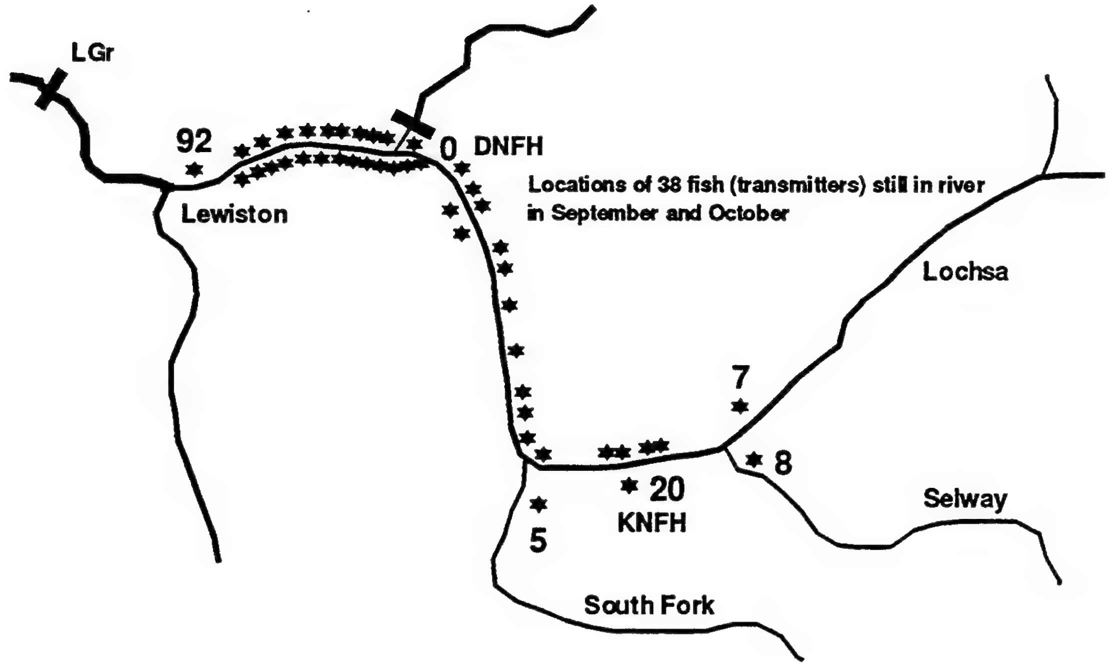

Figure 8. Map illustrating the final location of the 92 chinook salmon which entered the Clearwater River and its major tributaries during 1991.

Twelve chinook salmon (2.3%) were last located in the Snake River between Lewiston and Hells Canyon Dam (Table 1). Because this section of the Snake River has not been used by spring and summer chinook salmon for spawning, as far as we know, we have assumed that these fish died before spawning.

The Grande Ronde basin was the last location of 33 (6.2%) of the fish released with transmitters (Table 1). Fourteen fish were recorded entering the river on the receiver 1.6 km upstream from the mouth and not located again. Two fish were last seen in the Grande Ronde River, 11 entered Lookingglass Fish Hatchery, and the remaining 6 were located in other tributaries.

The Imnaha River was the last location for 16 (3.01%) chinook salmon released with transmitters (Table 1). Three fish were last recorded at the Imnaha River receiver located near Fence Creek 23 km upstream from the mouth, 4 fish were last recorded in the Imnaha River upstream from the receiver, and 8 fish were captured at the Imnaha River weir.

The Salmon River was the apparent destination of the largest proportion of the salmon released with transmitters, 223 of the fish (42.0%) were last located in that drainage (Table 1). Twenty-six fish (4.9%) were last recorded in the lower Salmon River from the mouth upstream 138.7 km to Riggins, and most of these fish probably died before spawning

because the lower Salmon River is not a spring or summer chinook spawning area. Fifty-four fish (10.6%) were located in the Little Salmon River tributary, 11 in the Little Salmon River, 10 in Rapid River, and 33 were caught at the trap and taken to Rapid River Fish Hatchery. Although most of the 54 fish were probably destined for the hatchery, many spawned in the streams downstream from the trap. Only seven fish were last recorded in the Salmon River between Riggins and North Fork, and most of those may have been fish that died before spawning.

The South Fork, the next major drainage up the Salmon River from Riggins, was the last location for 52 salmon (9.8%) (Table 1). Three were last recorded at the receiver site 1 km downstream from the mouth of the Secesh River, 31 were found in the main stem South Fork between the receiver site and the fish weir near Knox Bridge, 2 each were found in Johnson Creek and Secesh River, and 14 were captured at the weir. The was no way to estimate mortality within the South Fork.

Two fish with transmitters were found during spawning ground surveys in Chamberlain Creek, a tributary between the South and Middle Forks, and both fish had spawned successfully.

In the Middle Fork drainage, 13 fish were found in several tributaries and 16 fish were last recorded at the receiver at the mouth of the Middle Fork (Table 1). Because much of the drainage is unroaded, our coverage was less complete than in other basins. Some of the 16 fish may have died before spawning, but we do not know the number.

Of the 52 fish (9.8%) last recorded in the upper Salmon River basin upstream from North Fork, 22 were last recorded in the Salmon River, 6 were found in the Lemhi River, 1 in Hat Creek, 4 were recaptured at the Pahsimeroi Fish Hatchery, 6 were recaptured or located in the East Fork Salmon River, and 14 were trapped at the Sawtooth Fish Hatchery weir (Table 1). One of the fish found in the upper Salmon River had died unspawned, but several were recorded near spawning areas from Challis upstream to the Sawtooth weir.

In summary, the distribution of fish released with transmitters by sections or drainages in the Snake River basin in 1991 was as follows: 3% left the Snake River after release, 25% did not get upstream beyond the Lower Granite pool, 17% entered the Clearwater River, 2% were last recorded in the Snake River upstream from Lewiston, 6% were recorded in the Grande Ronde basin, 3% entered the Imnaha River, and 42% ended up in the Salmon River (Table 1). If we assume the fish lost in the Lower Snake River were destined for the tributaries in the same proportions as the survivors, then the distribution by Snake River tributary becomes 24.7% destined for the Clearwater River, 9% destined for

the Grande Ronde River, 4.3% destined for the Imnaha River, and 62% destined for the Salmon River.

An estimate of the number of fish with radio transmitters that died before spawning can be made on the basis of the last place the fish were located. Such estimates contain both negative and positive biases, because fish last located in a section of river where spawning has not been seen (usually main stems of the major tributaries) were counted as fish that died prematurely, and fish located in a spawning stream would be counted as a fish that spawned. In the first case, the fish may have spawned where located or in a tributary upstream, but was not detected. In the second case, not all fish that make it to a stream used for spawning survive and spawn.

Of the 508 tagged fish that we believe tried to migrate up the Snake River after released at Hood Park, 132 (26%) were not located upstream from the four lower Snake River dams and reservoirs (Table 1), and can probably be classed as fish that died prematurely. In the Clearwater River drainage, 51 of the 92 fish that were found in that basin were last seen in the main stem Clearwater River between the mouth and the Selway River. Spring and summer chinook salmon have not been seen spawning routinely in the river so most, if not all, of those fish died before spawning or entering the two hatcheries in that section of stream. If they were losses, they would increase the loss rate to 36% (183/508). The twelve fish last recorded in the Snake River between Lewiston and Hells Canyon Dam, another stretch with no history of spawning for these fish, would increase the loss to 38%. We know of only one fish that died before spawning in the Imnaha River and could not class any of the fish entering the Grande Ronde River as losses, although some probably occurred. In the Salmon River, 26 fish were last located downstream from Riggins, and 7 were last found between Riggins and North Fork, both stretches of river with no history of spawning. Twenty-two fish were last located in the Salmon River upstream from North Fork, and we believe many of those fish spawned, but know of two fish that were found dead and unspawned in that section of river. With the one fish from the Imnaha River and 35 fish from the Salmon River that could be classed as premature mortalities, the loss rate goes up to 46% (231/508). Some of the fish that entered the South and Middle Forks of the Salmon River may also have been losses, but we had no way of estimating the number. The estimated prespawning loss rate of fish with radio transmitters in 1991, at 46% plus or minus, is not too different from the loss calculated in a different way for prior years. Bjornn (1990) estimated that prespawning losses for wild spring and summer chinook salmon in the Snake River basin averaged 45% for the 1962-1968 period (only Ice Harbor Dam present), and 54% for the 1975-1988

period (all four dams in place). He estimated the number of wild spawners passing Ice Harbor Dam and compared that number with the number of spawners represented by the redds counted in the Snake River basin.

Spring versus summer chinook salmon distribution A comparison of the fish found in each drainage versus the time they were tagged and released at Hood Park provides an estimate of the distribution of spring versus summer chinook salmon throughout the Snake River basin. As pointed out previously, 305 (57%) of the fish released at Hood Park with transmitters were released in April and May, and 226 (43%) were released in June and early July. We have assumed that most of the fish released in April and May were spring chinook salmon and those in June and July were summer chinook salmon. Of the 432 records of fish passing Lower Granite Dam, 60% of the fish had been released in April and May and 40% had been released in June and July (Figure 9), virtually no change from the percentages at release, which is what we would expect unless there was a differential mortality for spring and summer chinook. The same distribution was true for fish captured in the Lower Granite adult trap.

Upstream from Lower Granite Dam, the distribution of spring and summer chinook salmon varied by tributary. Of the 92 fish with transmitters entering the Clearwater River in 1991, 76% were spring chinook salmon based on our 1 June cutoff date, and the rest were summer chinook salmon (Figure 9). Of the 290 fish heading up the Snake River and into tributaries upstream from Lewiston/Clarkston, 52% were spring chinook salmon and the remainder were fish of the summer run.

Within the Clearwater River basin, all of the fish recorded in the Lochsa and South Fork rivers were spring chinook salmon in 1991 (Figure 10). Fish going into the Selway River and recaptured at Kooskia NFH were a mixture of spring and summer chinook salmon, as were the fish that ended up dying, and perhaps spawning, in the main stem of the Clearwater River. The mixture of spring and summer chinook in the Selway River is not surprising because fish from spring and summer chinook salmon stocks in the Salmon River were transplanted to the Selway in the 1960's.

In the Grande Ronde and Imnaha river basins, both spring and summer chinook salmon entered the rivers (Figure 11). All but 7 of the 33 fish entering the Grande Ronde River were spring chinook salmon (79%), and the remainder were probably summer chinook salmon. Spring and summer chinook salmon were equally numerous in the Imnaha River. All of the fish that were recaptured at Lookingglass Fish Hatchery in 1991 were spring chinook salmon.

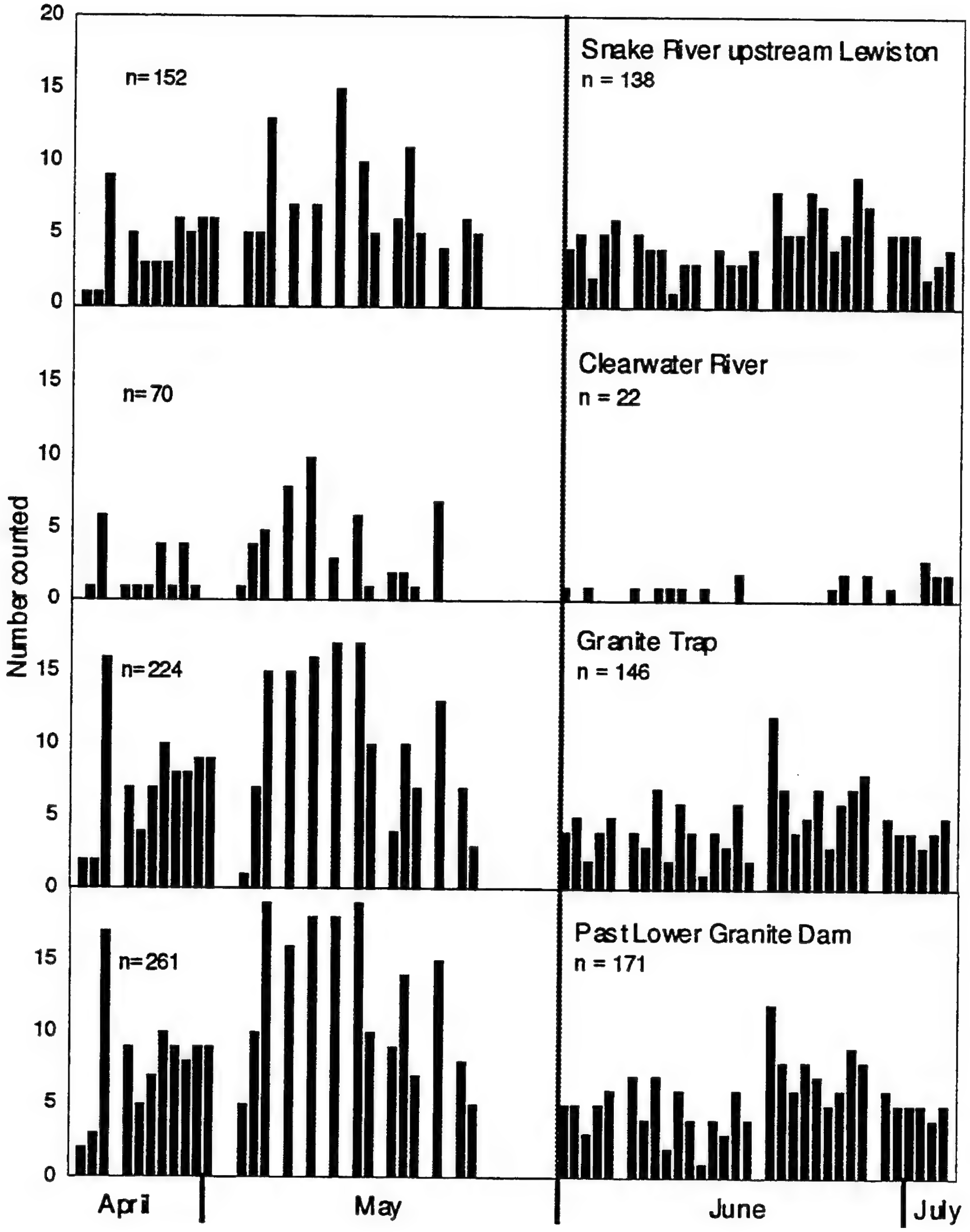

Figure 9. Frequency distribution of chinook salmon with transmitters passing Lower Granite Dam and entering the Clearwater and Snake River upstream from Lewiston based on time of tagging and release at Ice Harbor Dam in 1991.

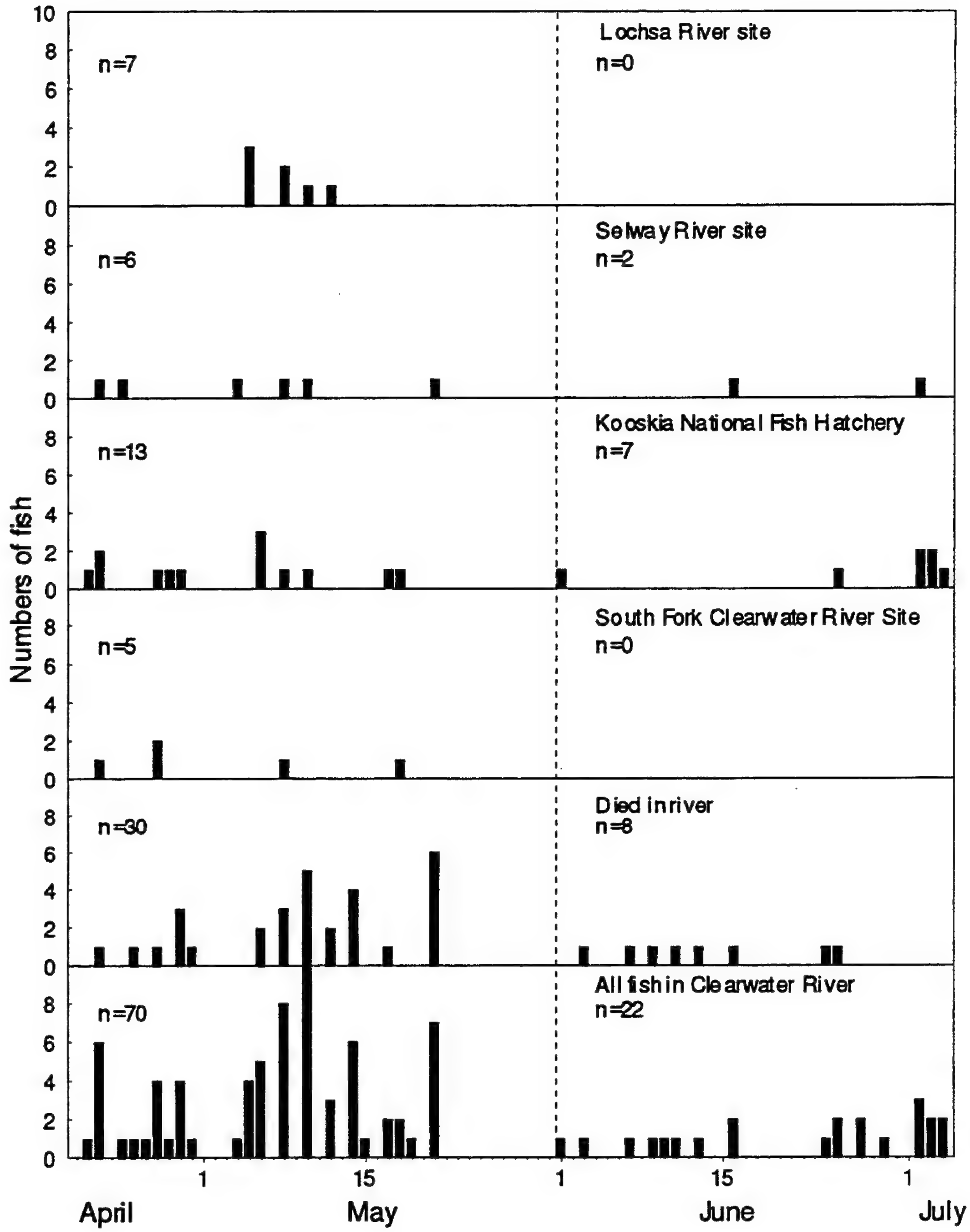

Figure 10. Frequency distribution of chinook salmon with transmitters entering the Clearwater River and tributaries and hatcheries within the basin based on time of tagging and release at Ice Harbor Dam in 1991.

Spring and summer chinook salmon with transmitters that entered the Salmon River were almost equally abundant in 1991 (Figure 12). Overall, 48% of the 224 fish entering the Salmon River were spring chinook salmon and the remainder were summer-run fish. Within the tributaries of the drainage, the proportion of spring or summer run fish varied widely. Nine of the 33 fish recaptured and taken into Rapid River Fish Hatchery were probably summer chinook salmon. Fish that were last located in Rapid River downstream from the hatchery and in the Little Salmon River (21 fish) were 81% spring and 19% summer chinook salmon.

In the South Fork of the Salmon River, a drainage previously thought to contain only summer chinook salmon, 8 of 52 fish could have been spring chinook salmon based on the time of realease at Hood Park (Figure 12). The two fish each recorded in Johnson Creek and Secesh River were summer chinook salmon. Six of the 36 fish recorded or recaptured in the South Fork downstream from the weir near Knox Bridge were classed as spring chinook salmon, as were 2 of 14 fish recaptured at the weir.

One of the two chinook salmon with transmitters recovered from Chamberlain Creek was a spring chinook salmon and the other was classed as a summer fish.

Fish with transmitters that we believe entered the Middle Fork of the Salmon River drainage were a mixture and spring and summer chinook salmon (Figure 12). All of the fish found in the upper tributaries of the Middle Fork (Sulphur, Marsh, Bear Valley, and Elk creeks) were spring chinook salmon. The single fish found spawned out in Loon Creek, near the Falconberry landing field, was a spring chinook, but it was found in an area previously thought to be used mainly by summer chinook salmon. The summer chinook salmon were found in Big Creek and among those last recorded in the main stem Middle Fork.

Of the 52 fish last located upstream from the receiver at North Fork on the Salmon River, 40% were spring and 60% were summer chinook salmon (Figure 12). All six of the fish located in the Lemhi River were spring chinook salmon. Of four fish recaptured at the Pahsimeroi Fish Hatchery, one was a spring and three were summer chinook salmon. Five of the six salmon located in the East Fork of the Salmon River were summer chinook salmon. Of the 14 fish recaptured at the Sawtooth Hatchery weir in 1991, 6 were likely spring chinook salmon and 8 were classed as summer chinook salmon. Many of the fish last located in the upper Salmon River were summer chinook salmon that spawned in the river between Challis and the Sawtooth Fish Hatchery weir.

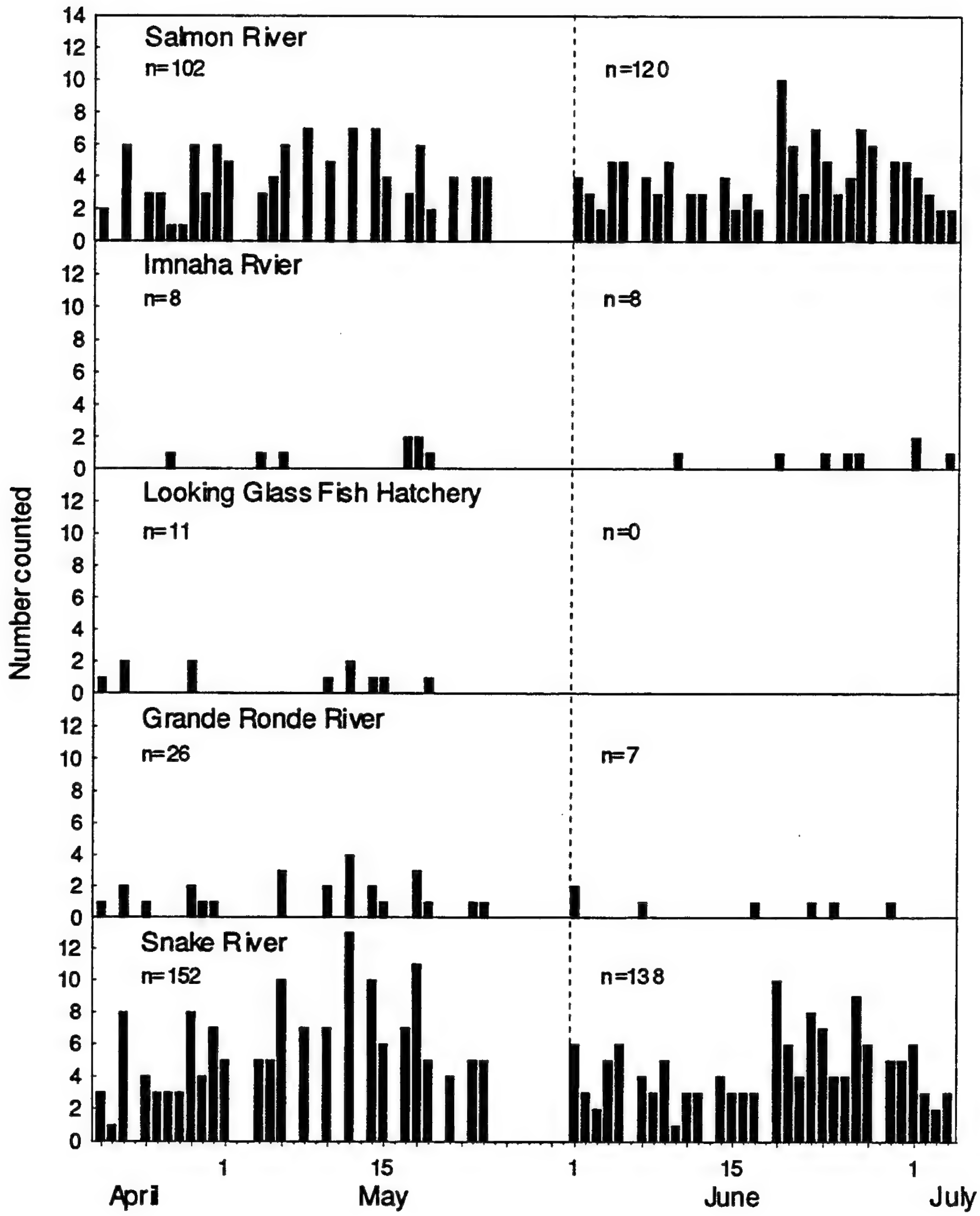

Figure 11. Frequency distribution of chinook salmon with transmitters entering the Snake River, tributaries, and hatcheries between Lewiston and the mouth of the Imnaha River based on time of tagging and release at Ice Harbor Dam in 1991.

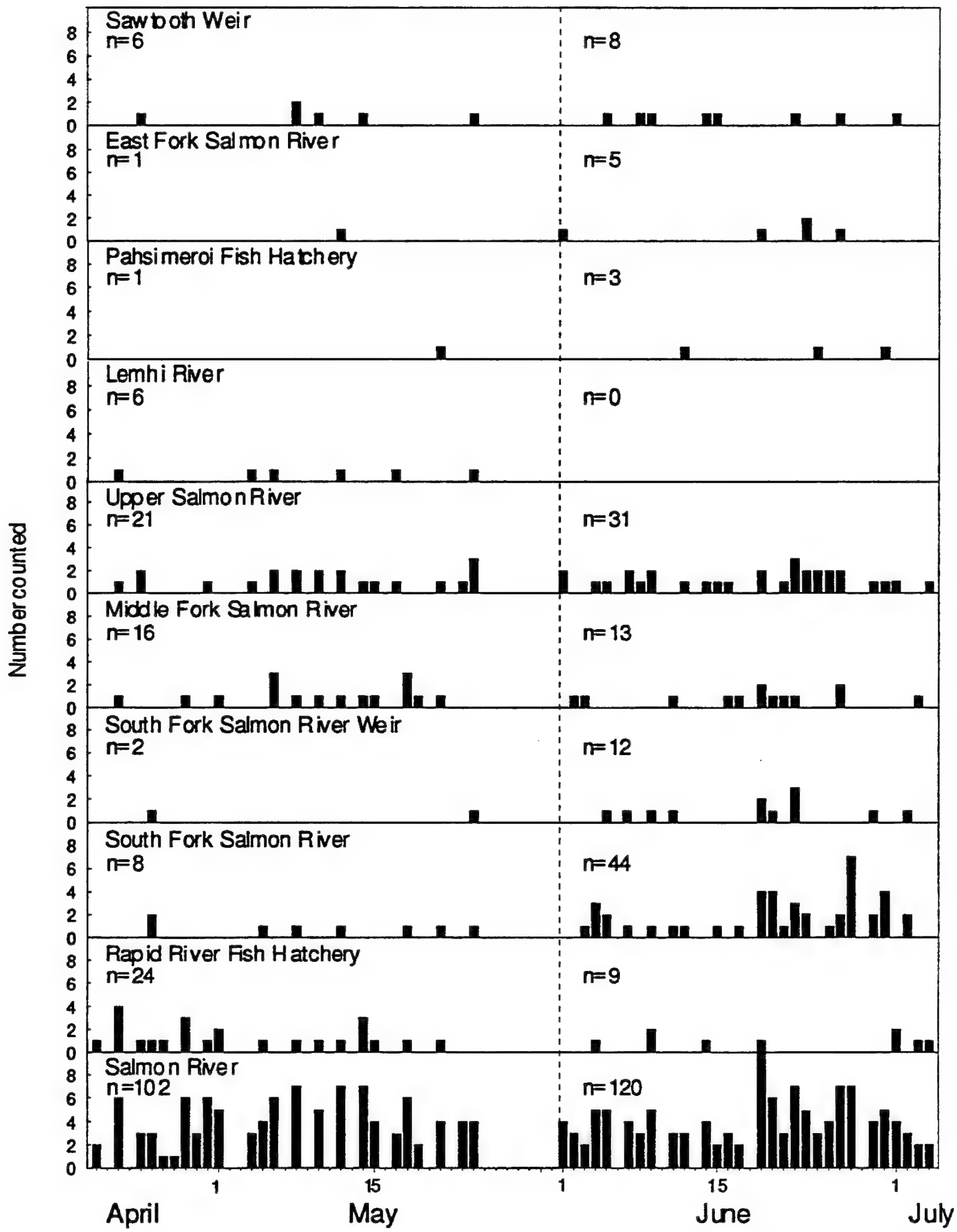

Figure 12. Frequency distribution of chinook salmon with transmitters entering the Salmon River, tributaries, and hatcheries based on time of tagging and release at Ice Harbor Dam in 1991.

Regurgitation of transmitters was monitored for 6 to 12 hours following tagging before the fish were released and we found that 20 of the 531 fish released (3.8%) disgorged their transmitters while in the recovery tank. The regurgitated transmitters were put in another fish. The regurgitation rate was similar after release, 14 of 370 chinook salmon checked at the Lower Granite adult trap (3.8%) had disgorged their transmitters since release at Hood Park. The last check on regurgitation rate was for the fish recaptured at weirs and hatcheries. Three of 55 salmon (5.5%) recovered at hatcheries or spawning grounds, with unquestioned data on transmitter status, did not have transmitters when they should have. The initial regurgitation of transmitters was compensated for by placing the transmitters in another fish. Fish that regurgitated their transmitters after release were partially accounted for if they were recaptured with the jaw tag attached at the Lower Granite adult trap, at hatcheries or weirs, and during spawning ground surveys. A fish that regurgitated a transmitter in a non-traditional spawning area and then proceed upstream to spawn undetected, would be counted as a loss. Such fish, if properly accounted for, would not reduce the loss rate more than 3-5%, in our opinion.

Migration rates.-The time spring and summer chinook salmon took to pass the four lower Snake River dams in 1991 varied from a high of 7.9 d on average at Ice Harbor Dam to a low of 1.8 d at Little Goose Dam (Table 2). Time required for a fish to pass a dam was measured as the lapsed time from the last record of a fish at the receiver downstream from the dams to the last record from the same fish on a receiver/antenna at the top of the ladders. The distribution of passage times was much more spread out at Ice Harbor Dam compared to the other three dams (Figure 13), and reflected the fact that many fish took several days to enter the fishway and pass up through the ladders. Nearly a third of the fish took more than 10 days to pass Ice Harbor Dam versus less than 5% taking that long at the other dams. At the three upstream dams, most of the fish passed over in less than 4 d. Fish may have taken longer to pass Ice Harbor and Lower Granite dams because of the traps operated in the south ladders of both dams, and perhaps because of confusion at being taken back downstream to Hood Park for tagging and release. The relatively low and similar rates of passage at Lower Monumental and Little Goose dams is an indication that the nighttime spill for smolts at Lower Monumental Dam in 1991 had little, if any, effect on upstream migrating adults. A more detailed analysis of the telemetry records will be conducted during 1992 and presented in the next report. Improved siting of receivers and antennas within the fishway during 1992 will allow us to evaluate where fish are spending the time while passing each dam.

Table 2. Mean and median number of days to migrate from the Hood Park release site to the tailrace of Ice Harbor Dam and the days to pass each of the four dams in the Lower Snake River.

	Number of fish	Mean number of days	Range of days	Confidence intervals (95%)	Median number of days
Hood Park to Ice Harbor	500	1.4	0.06-36.7	0.06-2.8	0.6
Past a dam					
Ice Harbor	195	7.9	0.07-48.9	0.07-16.0	5.4
Lower Monumental	193	2.2	0.05-33.8	0.99-3.4	0.7
Little Goose	212	1.8	0.07-31.3	0.07-8.6	0.8
Lower Granite	213	3.1	0.23-35.0	0.23-11.9	1.6

Spring and summer chinook salmon migrated quickly through the Snake River reservoirs on average in 1991, a year with relatively low clear runoff flows (Table 3). Fish migrated from the Ice Harbor Dam forebay to the Lower Monumental Dam tailrace in 1.6 d on average (56 km/d), through the Lower Monumental pool in 1.1 d (61 km/d), through the Little Goose pool in 1.1 d (63 km/d), and through the Lower Granite pool to the lower Clearwater River and Snake River receiver sites in 3.7 and 2.0 d (47 and 34 km/d), respectively.

The average rates of passage of fish through the four reservoirs were 1.8 d per reservoir and 55 km/d for fish entering the Clearwater River, and 1.4 d per reservoir and 58 km/d for fish moving on up the Snake River. The distributions of migration rates tended to be skewed to the right with a few fish taking a relatively long time to migrate from dam to dam, but most of the fish passed between dams in less than 2 d (Figure 14). Migration rates of fish through the Lower Granite pool appeared to be slower than through the three downstream pools, but the Lower Granite pool reach includes a few kilometers of the Clearwater (receiver at river km 7.5) and Snake (receiver at river km 237.1) rivers upstream from the end of the pool. Turbidities may have been higher in the Lower Granite pool and both of the rivers at times during the migration season and been a factor in the

slower migration rate. The mean time to migrate from the Ice Harbor Dam tailrace to the Lower Granite Dam forebay (four dams and three reservoirs) was 20.8 d (11.6 km/d).

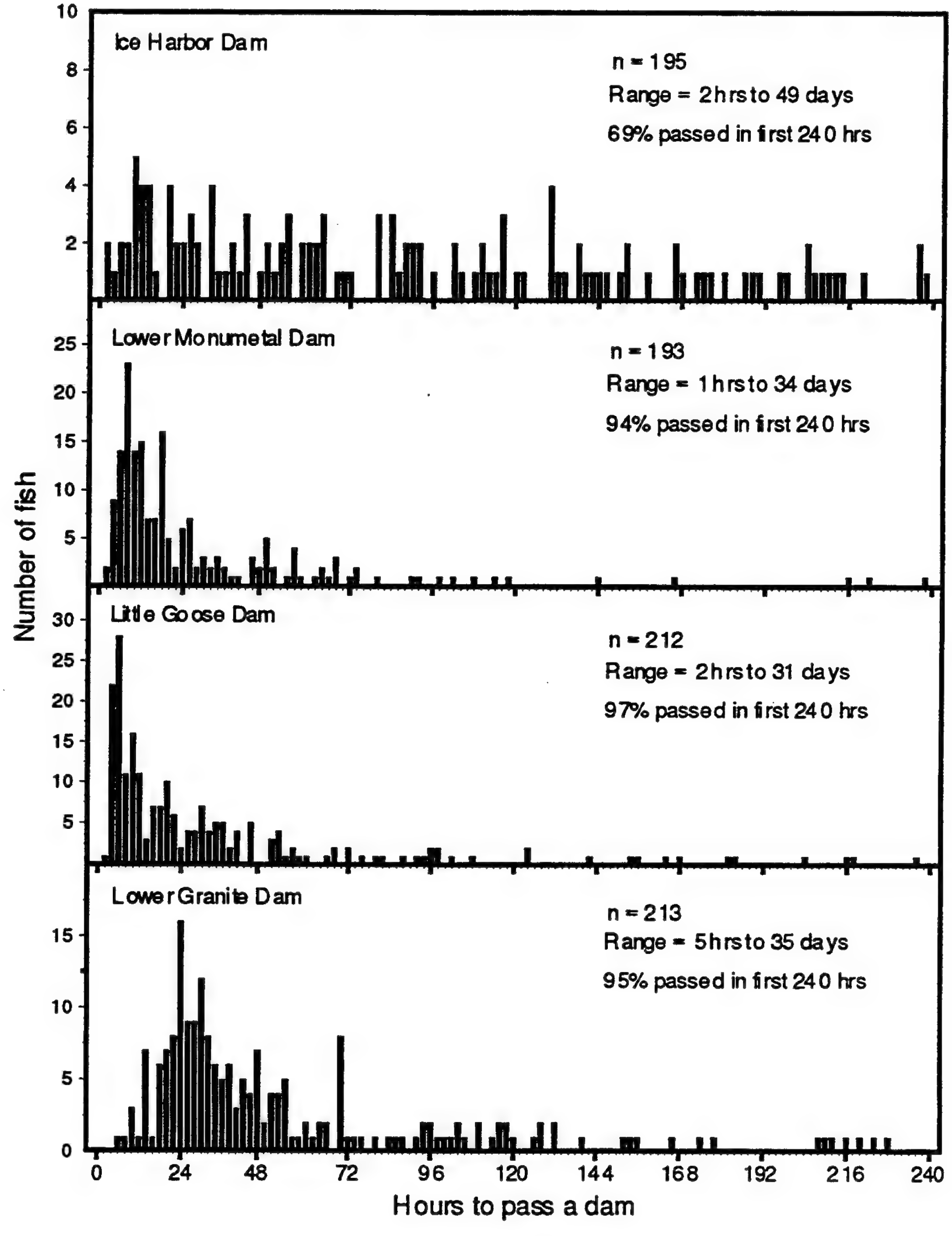

Figure 13. Frequency distribution of time to pass the four dams in the lower Snake River by spring and summer chinook salmon with radio transmitters in 1991.

Table 3. Migration rates of chinook salmon through reservoirs and in free flowing sections of river in 1991 as measured by fish recorded at receivers at the dams and at fixed-location sites in the rivers.

Section of river	Number of fish	Mean travel rates		Confidence interval (a=0.05)	
		Days	Km/day	Days	Km/day
Through reservoirs					
Ice Harbor to Lower Monumental dams	180	1.6	56.0	(0.5-7.3)	(13.1-99.3)
Lower Monument to Little Goose dams	172	1.1	61.0	(0.5-5.0)	(25.6-96.4)
Little Goose to Lower Granite dams	211	1.1	62.5	(0.6-2.7)	(32.2-92.8)
Lower Granite Dam to Clearwater River site	79	3.7	34.0	(0.7-14.2)	(2.1-76.2)
Lower Granite Dam to Snake River site	161	2.0	47.0	(0.6-7.6)	(7.5-86.5)
Ice Harbor Dam to Clearwater River site	---	1.8	54.9	---	---
Ice Harbor Dam to Snake River site	---	1.4	58.2	---	---
Through rivers					
Snake River to Grand Ronde River sites	28	1.9	31.0	(0.7-5.1)	(6.3-60.7)
Snake River to Lower Salmon River sites	117	10.7	25.1	(3.7-22.2)	(5.0-48.0)
Lower Salmon to South Fork Salmon sites	36	9.6	15.6	(5.6-17.8)	(5.9-25.4)
Lower Salmon to Middle Fork Salmon sites	72	8.6	25.7	(4.2-20.7)	(8.5-42.9)
Middle Fork Salmon to Upper Salmon sites	42	3.2	21.3	(2.0-8.5)	(9.8-32.9)
Upper Salmon site to Sawtooth weir	11	33.1	8.7	(16.6-1.5)	(4.1-15.6)

Examples of two extremes in migration of chinook salmon through the Lower Snake River are those portrayed in Figure 15. The fish portrayed in the upper diagram migrated rapidly from Hood Park to Ice Harbor Dam, past each of the upstream dams, and passed over Lower Granite dam only 5.5 d after release (an average migration rate of 33 km/d including dams and reservoirs). The fish portrayed in the lower diagram also moved rapidly back up to Ice Harbor Dam after release, but then took several days to pass the dam. Migrations rates past the three upstream dams were within the normal 1-3 d range (Bjornn and Peery 1992), and the fish ultimately took 25.1 d to migrate from Hood Park to the Lower Granite Dam forebay. The fish then fell back through Lower Granite Dam, moving down to Little Goose Dam, then back up to Lower Granite Dam, back down to and through Little Goose Dam, down to and through Lower Monumental Dam, and finally was lost in the Ice Harbor pool.

Fallback over the dams by chinook salmon did not happen often in 1991 because of the low flows and lack of spill. The rate of fallback and reascension at Lower Granite Dam, based on recaptures of tagged fish at the adult trap, was 4.9% (18 of 370 fish fell back and then migrated back over the dam). The mean time till reascension was 6.0 d, with a range of 1 to 21 d, and the median days till reascension was 5. One fish fell back twice and took 21 d for the first reascension and 2 d for the second. Most of the fish fell back through the turbines and were not collected in the juvenile facility. Fallback rates at all four dams based on radio tracking data is still being analyzed.

Migration rates of fish in the free-flowing sections of the Snake, Clearwater, and Salmon rivers were slower than those of fish in the reservoirs (Table 3). In the free-flowing rivers, salmon migrated at mean rates of 16 to 31 km/d versus an average rate of nearly 60 km/d through the three reservoirs between dams, and 55-58 km/d when the Lower Granite pool was included in the average. Factors that may have contributed to the slower rates of migration in the free-flowing rivers include higher velocities and turbidities in the rivers than in the reservoirs, and, in some reaches, a slowing of migration as fish approached their natal stream.

Steelhead - Migration Rates and Passage Success

Methods

Migration rates and passage at the dams and into the tributaries of the Snake River were assessed for steelhead in a similar manner as was described for chinook salmon. The receivers set up to monitor chinook salmon movements at the dams and mouths of the major tributaries were also used to monitor steelhead movements, and some additional

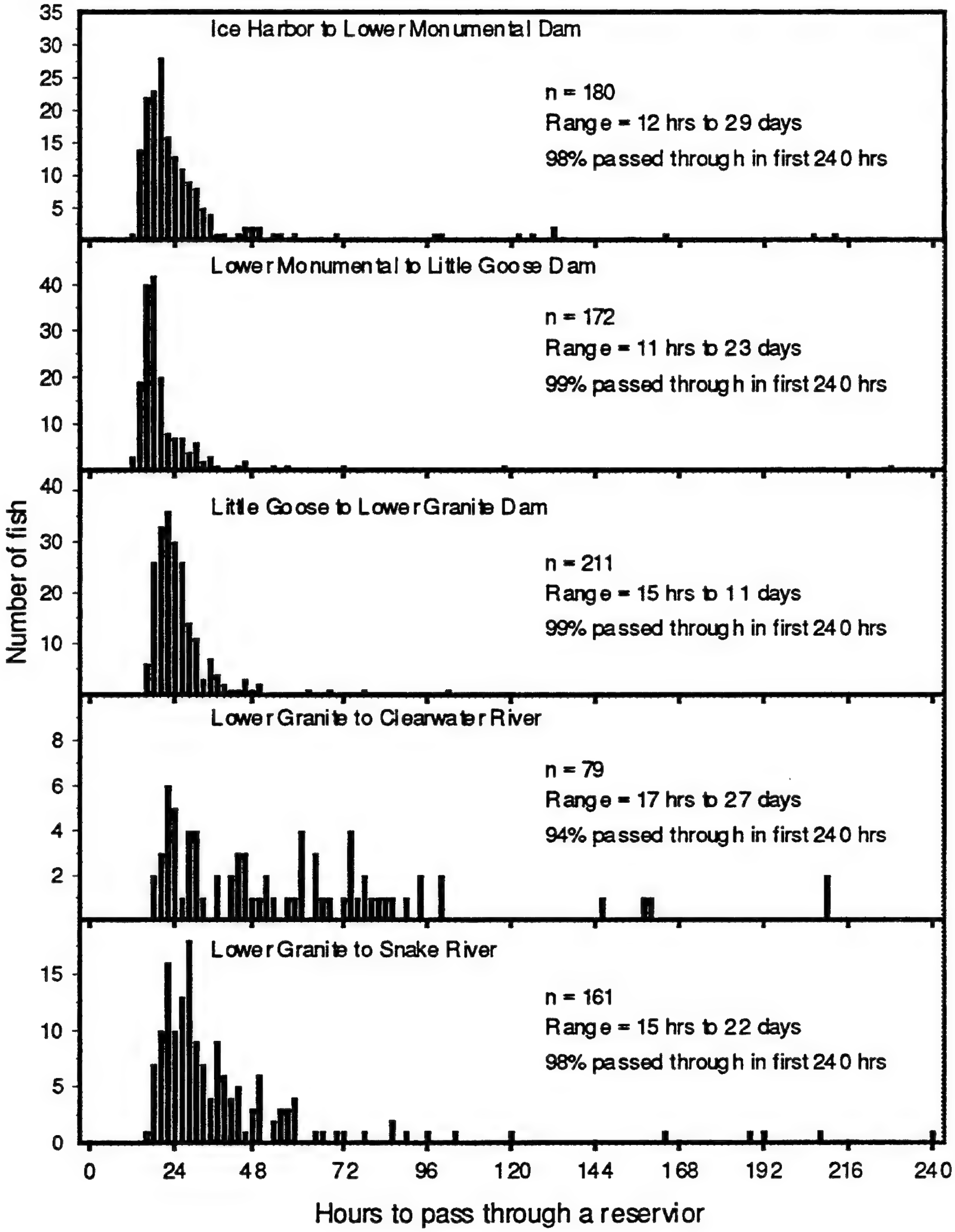

Figure 14. Frequency distribution of time to pass through the four reservoirs in the lower Snake River by spring and summer chinook salmon with radio transmitters in 1991.

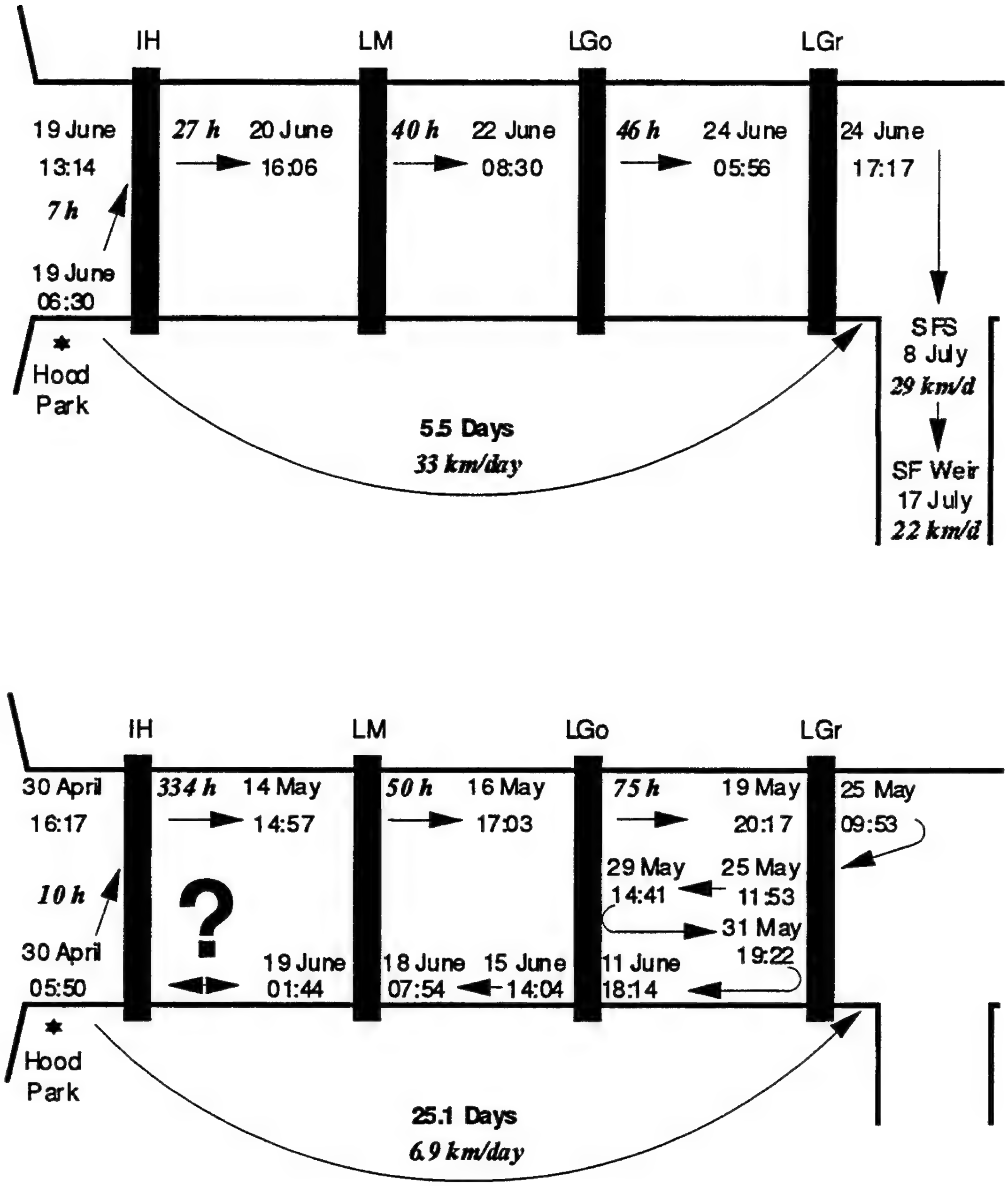

Figure 15. Examples of a chinook salmon that passed rapidly through the lower Snake River and a fish that migrated over Lower Granite Dam, but then moved between and over dams until it was lost in the Ice Harbor Pool.

receivers were added at the top of the ladders in July at each dam (sites labelled IH5, LM5, GO5, GR5, Figure 2) to increase the chances of recording each fish passing over the

dams. Underwater antennas in the fishway were modified in September by looping the cable into several pools to extend their range.

Capture and outfitting steelhead with transmitters at Ice Harbor Dam began in early July in an attempt to evaluate some pile driving near Lower Granite Dam. During July, 210 steelhead were captured, outfitted with transmitters, jaw tagged, and released at Hood Park (Figure 16). The pile driving was completed more quickly than anticipated so we were unable to evaluate the effect of pile driving on steelhead movements. The fish released in July were nonetheless tracked and provided information on movements of steelhead from the early segment of the run into the Snake River. Water temperatures in the river and the fishways at the dams exceeded 20^{o}C during the latter part of July, August, and early September (see later section).
For that reason, few fish entered the Snake River and no more steelhead were trapped and released with transmitters until water temperatures declined and fish started moving in September.

During September, October, and November, another 518 fish were released with transmitters at Hood Park and Charbonneau Campground, with the latter located 1.7 km upstream from the dam. Steelhead were released upstream from the dam to evaluate the effect of the Hood Park release site on subsequent migrations back into the Columbia River or up over Ice Harbor Dam as they continued up the Snake River.

A major difference between the steelhead and chinook salmon portions of the telemetry work, was the presence of an active fishery in most of the Snake River where steelhead migrated. Anglers captured many of the fish with transmitters and often turned in the transmitter and jaw tag to provide information and get the $5 reward.

Results

At the time this report was prepared (March-May 1992), many steelhead had been caught by anglers, some had entered Hatcheries, most had migrated past the four dams in the lower Snake River, and some were still migrating upstream. The information we present will be incomplete and conclusions should be drawn with caution.

By 12 May 1992 we had processed 710 reported captures of tagged steelhead by anglers in the fisheries in Washington, Oregon, and Idaho. The 710 recaptures amounted to about 22.5% of the 3,151 tagged fish released (728 with transmitters, 1,976 with spaghetti tags, 442 with only jaw tag that were captured in the Lower Granite juvenile collection system, and 5 with only a jaw tag because they regurgitated transmitter at time of tagging). A small number of additional recaptures from the fisheries will be processed and reported in the next report.

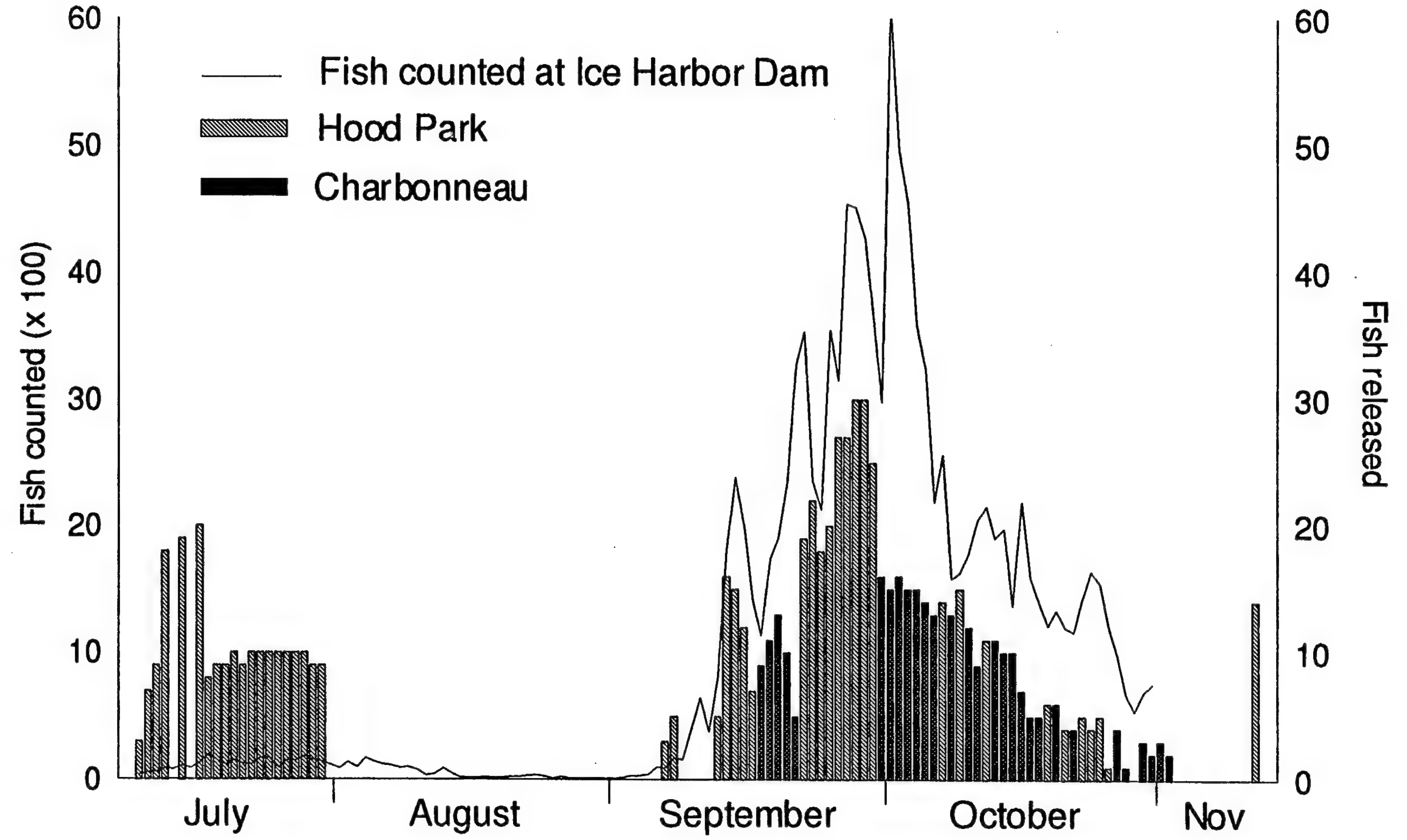

Figure 16. Comparison of the steelhead counted at Ice Harbor Dam and the number of steelhead tagged and released at Hood Park and Charbonneau each day during 1991.

Of the 710 steelhead reported caught so far, 31 had moved downstream into the Columbia River after release and 21 were caught there, and 10 others were caught after having moved up into the Walla Walla River (Figure 17). The largest number of recaptures, so far, have been from the lower Snake River (mouth to Lewiston) where 226 were caught from the Snake River and 11 from the Tucannon River. Another 107 fish were caught from the Snake River between Lewiston and the Salmon River, and 8 fish upstream from the Salmon River.

In the Clearwater River basin, 100 steelhead were reported caught from the main stem Clearwater River and 31 from the North Fork (Figure 17). Recaptures by anglers fishing the Grande Ronde River have added up to 45 so far, and 2 from the Imnaha River. Anglers fishing the Salmon River have reported catching 149 tagged steelhead.

At the Lower Granite adult trap 2,056 fish were recaptured in the fall of 1991 and 167 fish through 28 April in the spring of 1992 (Table 4). A portion of these fish were repeat recaptures. Analysis of the repeat recaptures will be completed after all data has been collected and will be separated into fish with transmitters versus those with spaghetti-loop tags and only jaw tags.

Reported recaptures at hatcheries were not complete, but we can report that 8 tagged steelhead had been taken into Lyons Ferry Fish Hatchery, 50 into Dworshak, 1 into Kooskia, 19 into Pahsimeroi, and 25 into Sawtooth (Table 4). We expect additional returns to be reported after spawning is completed.

Movement of steelhead back into the Columbia River after being outfitted with transmitters and released at Hood Park occurred among fish released in July and September of 1991. In a radio tracking survey of the Columbia River from McNary to Priest Rapids dams conducted in October, we found 53 steelhead that had moved back downstream. Of the 210 steelhead outfitted with transmitters and released in July, 29 were found in the Columbia River upstream from the Snake River, six downstream, and 5 in the Snake River downstream from Ice Harbor Dam (Figure 18). Eighteen fish released with transmitters in September were also found in the Columbia River during the October survey.

Steelhead - Zero-Flow Test

Methods

A comprehensive large-scale test of the effects of reducing flows at night to near zero in the lower Snake River on steelhead migrations was launched in September. The effects of zero flow at night on steelhead in the lower Snake River will be evaluated by monitoring

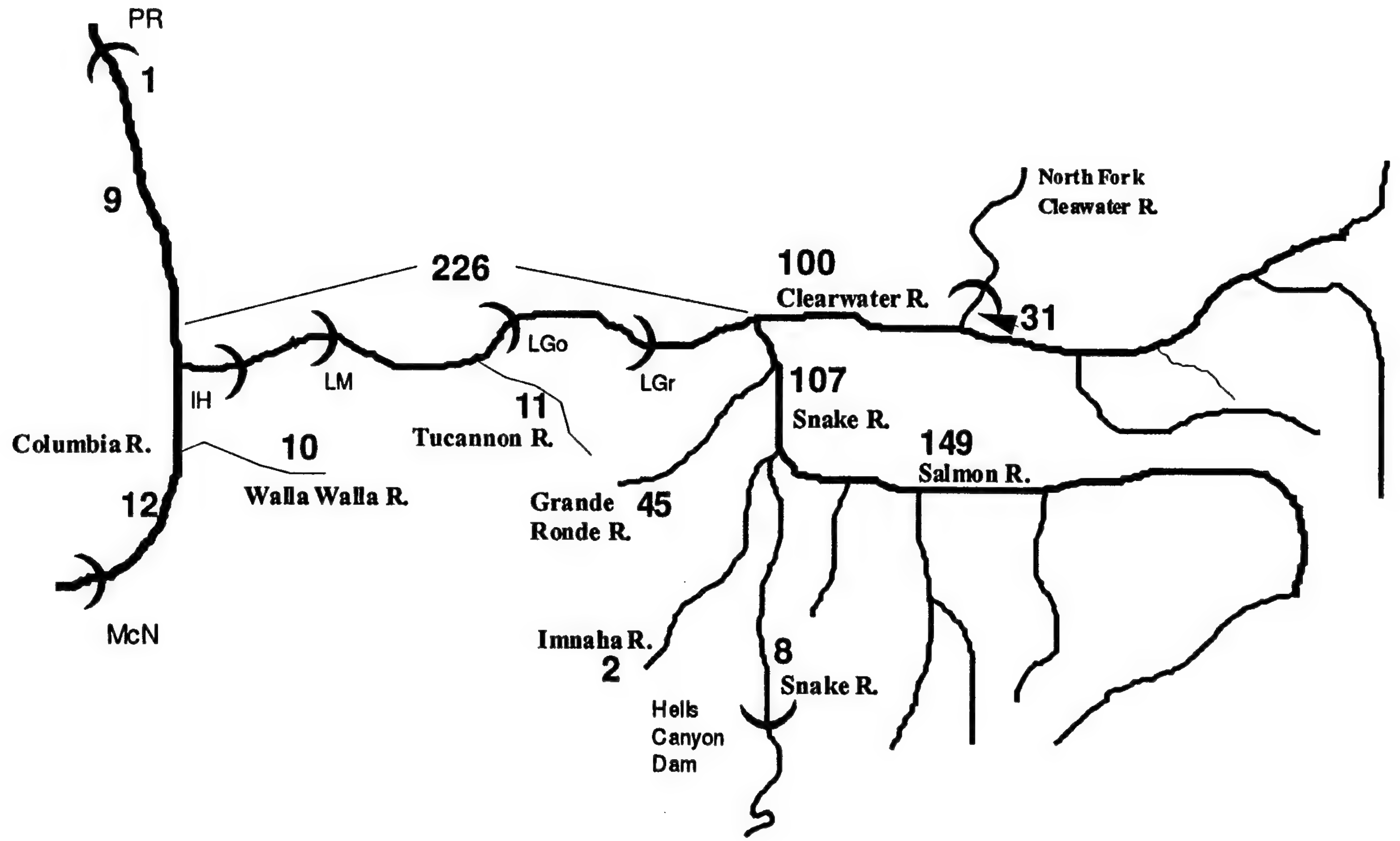

Figure 17. Distribution of steelhead caught by anglers in fisheries in Washington, Oregon, and Idaho during the fall of 1991 through the spring of 1992 (reports of recaptures not complete).

the migrations of the fish with transmitters, and more importantly, the four groups of steelhead tagged and released at Charbonneau Campground at the start of four two-week periods with either zero or normal flow at night.

Table 4. Recaptures of steelhead tagged and released at Hood Park Campground or Charbonneau Campground near Ice Harbor Dam that had been processed through 12 May 1992.

Recapture location	Type of recapture	Number of fish
Columbia River		
Upstream from Snake River	Fishery	9
Priest Rapids Dam	Trap	1
Downstream from Snake River	Fishery	12
	Found Dean	3
Walla Walla River	Fishery	10
	Subtotal	35
Snake River		
Mouth to Lewiston	Fishery	226
Lyons Ferry Hatchery	Trap	8
Tucannon River	Fishery	11
Lower Granite Adult Trap	Trap	2,223
Lewiston to Salmon River	Fishery	107
Clearwater River	Fishery	100
North Fork	Fishery	31
Dworshak Fish Hatchery	Trap	50
Kooskia Fish Hatchery	Trap	1
	Subtotal	182
Grande Ronde River	Fishery	45
Salmon River	Fishery	149
Pahsimeroi Fish Hatchery	Trap	19
Sawtooth Fish Hatchery	Trap	25
	Subtotal	193
Imnaha River	Fishery	45
Salmon River to Hells Canyon Dam	Fishery	8
Hells Canyon Dam	Trap	2
	Total	3,042

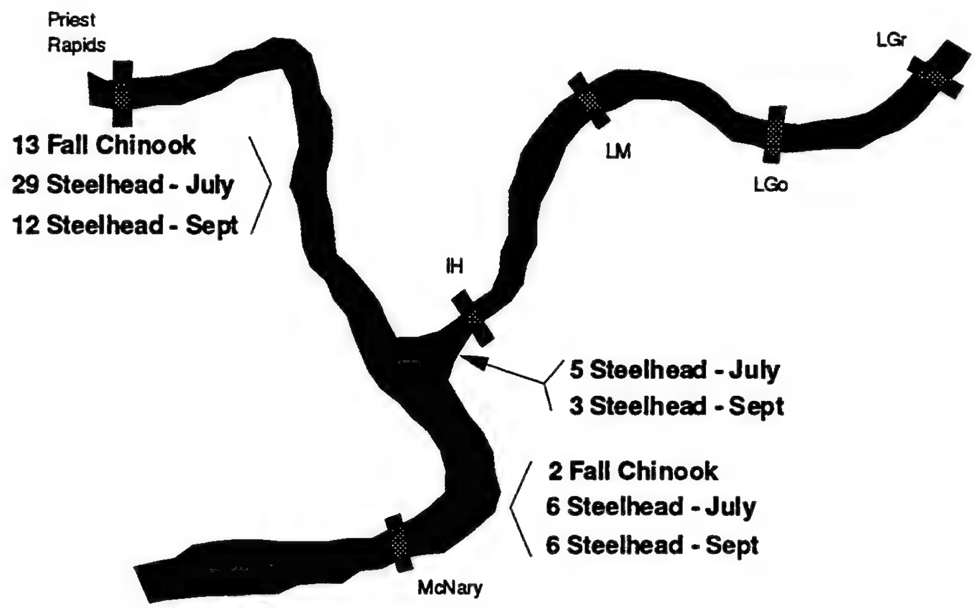

Figure 18. Distribution of steelhead located during a radio tracking survey of the Columbia River from McNary to Priest Rapids dam conducted in October, 1991. Distributions are presented for fish tagged and released in July and September.

The zero-flow test was delayed in 1991 until mid September when river temperatures had declined enough that steelhead began to enter the Snake River in large numbers. The first two-week period ran from 16 to 29 September; flows were cut to near zero at Lower Granite, Little Goose, and Lower Monumental dams from about 2300 to 0600 hr each night; and 471 fish were captured, tagged with both a spaghetti loop (orange color) and jaw tag, and released upstream from Ice Harbor Dam during the first five days of the period (Figure 19). The next three two-week periods alternated from normal flow at night, to zero flow, to normal flow. About 500 steelhead were tagged (different color for each period) and released at the start of each period.

The flows at night during the zero-flow test, were decreased at the three upper dams to near zero by shutting down all turbines (ladder flows, and lockages added a small flow at each dam) starting about 2300 hr and continuing until about 0600 hr for each two weeks of zero flow, versus nighttime flows of about 1100 cfs during each two weeks of normal flows (Figures 20 and 21).

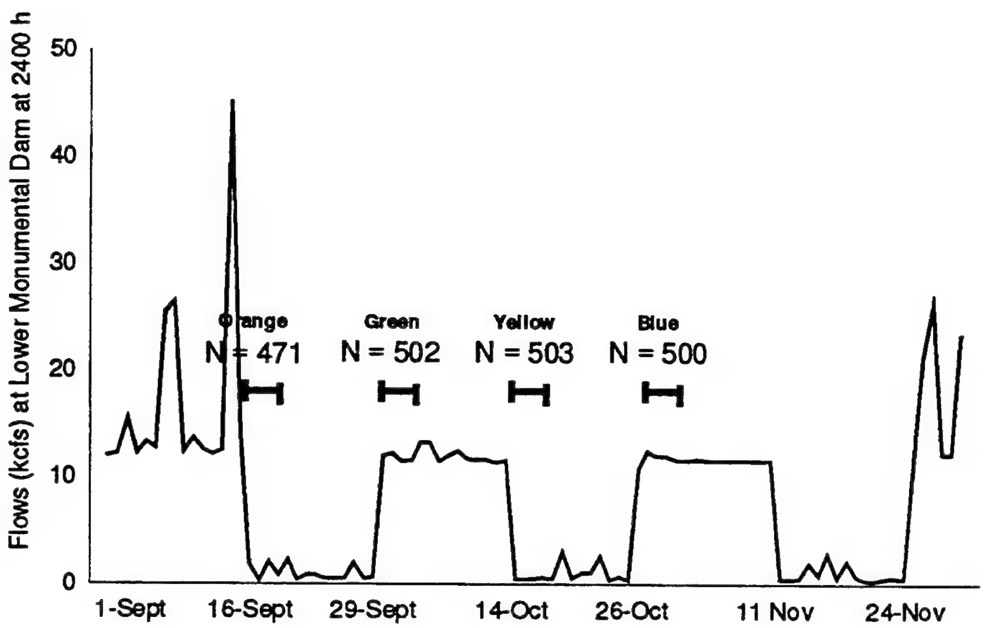

Figure 19. Pattern of flow at night at Lower Monumental Dam during the 1991 zero-flow test, and the numbers of steelhead tagged and released during the four two-week test periods.

Migrations of the steelhead tagged for the zero-flow study were monitored by: (1) the people counting fish at all four dams (number of fish with each color of loop tag by day); (2) recaptures at the adult trap in the Lower Granite Dam ladder; (3) date, time, and location of recapture in the fisheries; (4) date and number recaptured at hatcheries from each group; and (5) the movements of fish with radio transmitters during the zero and normal flow periods.

Results

Two types of data on steelhead movements during the zero-flow test in the fall of 1991 have been summarized and presented in preliminary form, the numbers of fish with spaghetti-loop tags counted at the counting windows of the three dams upstream from Ice Harbor Dam, and the numbers of loop-tagged fish captured in the adult trap at Lower Granite Dam. Data from the fish with radio transmitters released during the test, recaptures in the fisheries, and recaptures at the hatcheries are not complete and will be presented in later reports.

Fish counted at the dams Steelhead in the first three groups tagged with spaghetti-loop tags and released for the zero-flow study moved upstream and passed over the three

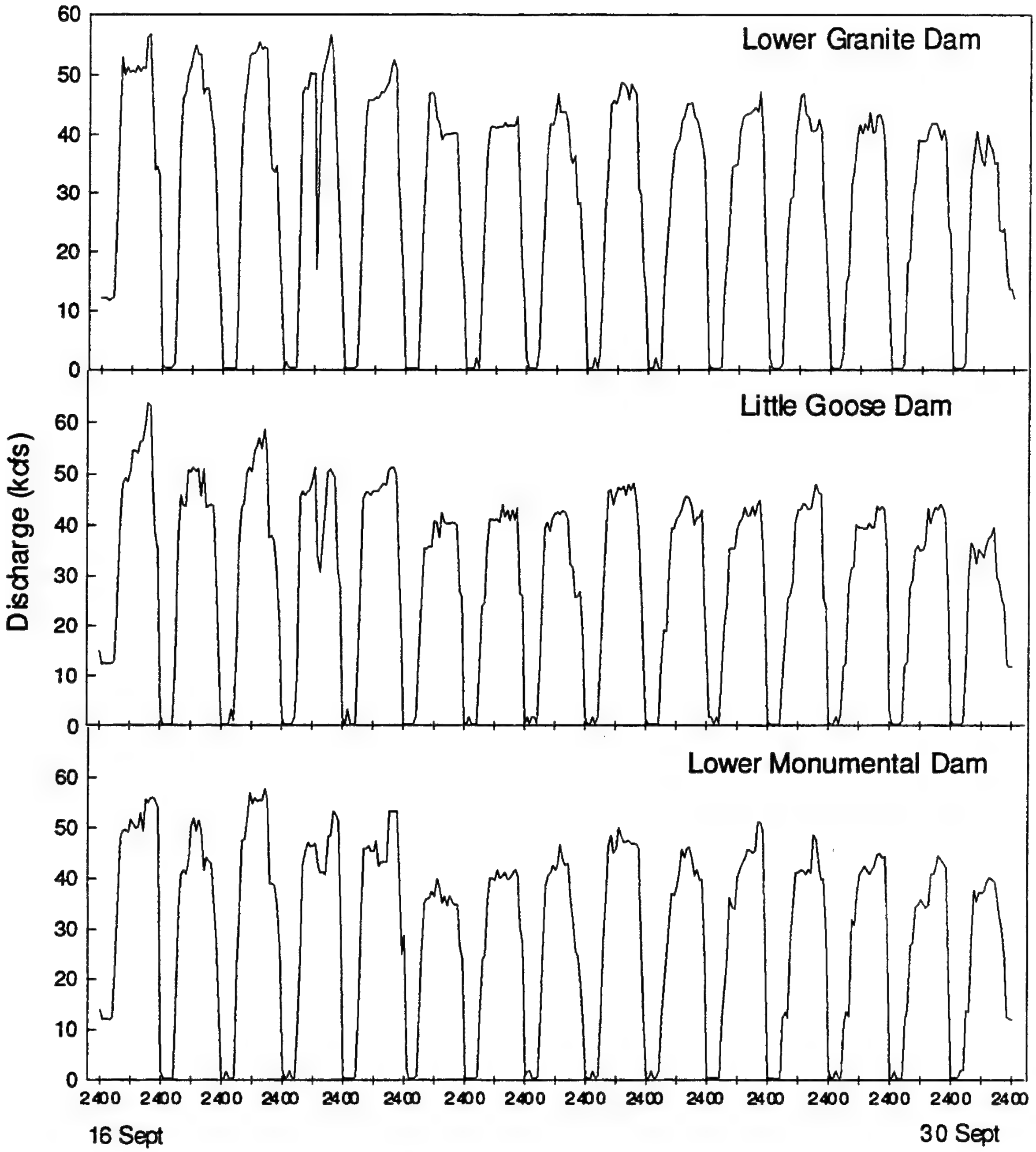

Figure 20. Discharges from the three upper dams in the lower Snake River during the two-week period in September 1991 when flows were reduced to near zero from about 2300 to 0600 hr each night.

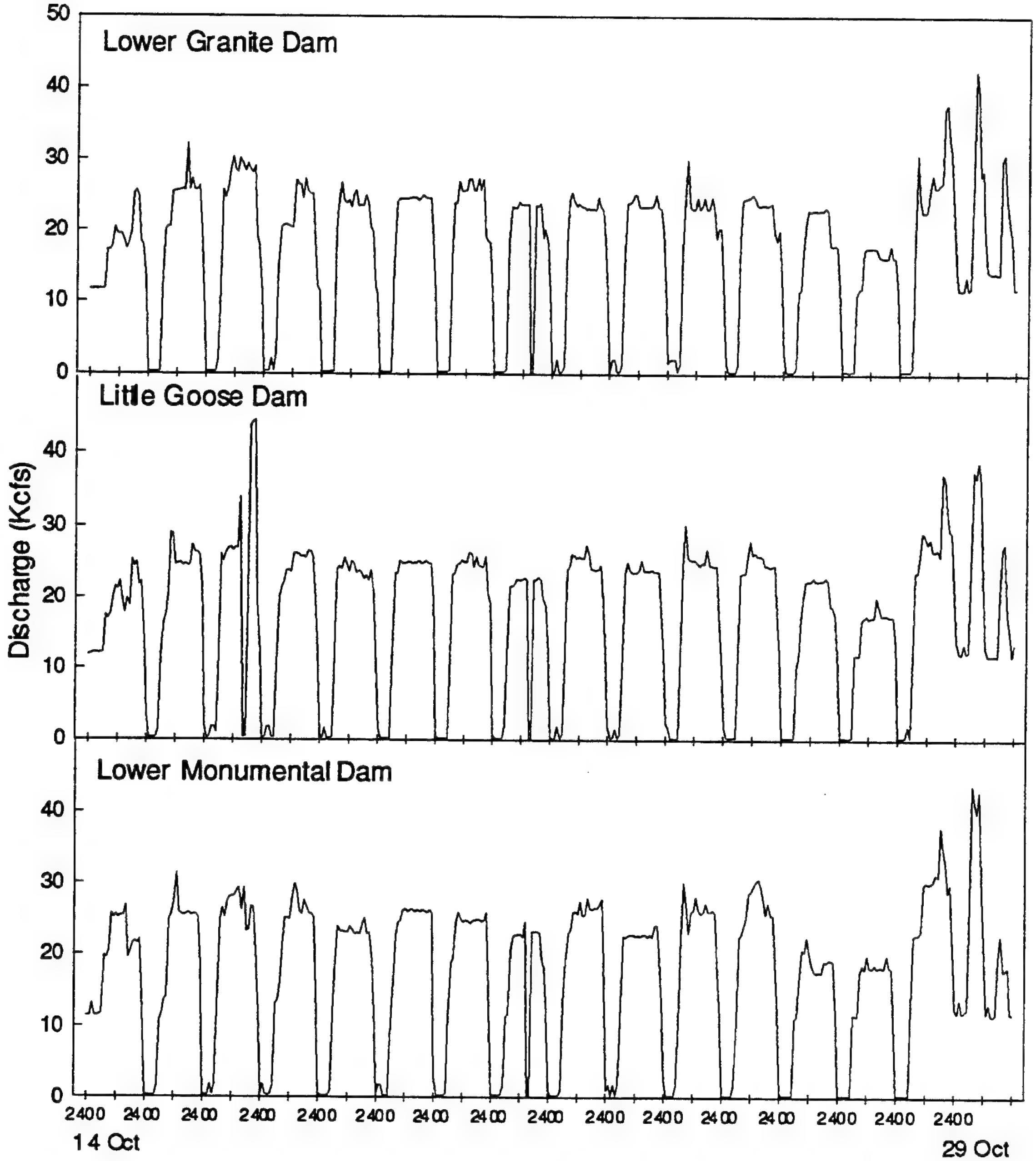

Figure 21. Discharges from the three upper dams in the lower Snake River during the two-week period in October 1991 when flows were reduced to near zero from about 2300 to 0600 hr each night.

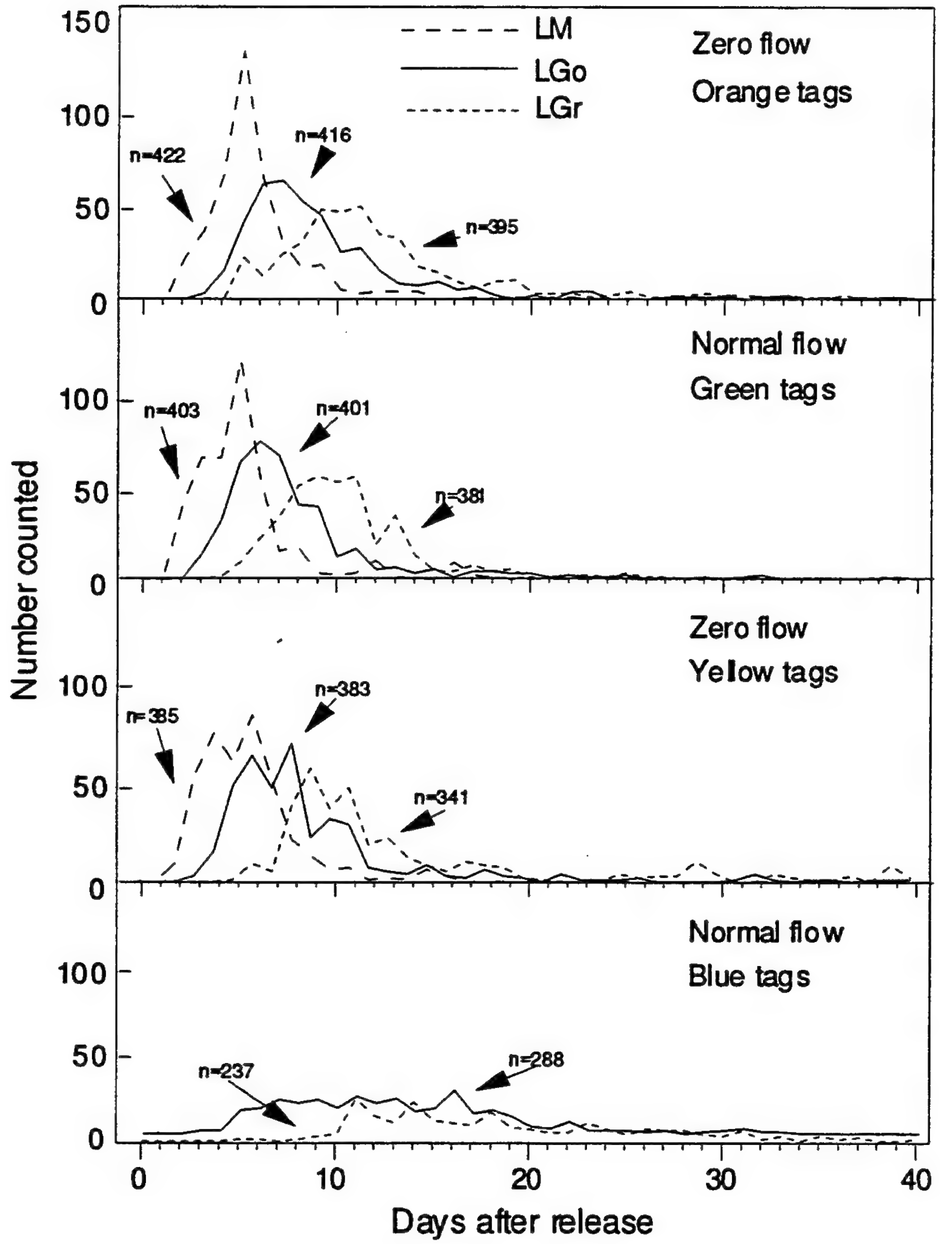

Figure 22. Frequency distribution of steelhead with spaghetti-loop tags that were counted at the three upper Snake River dams up to 40 d after release to illustrate the timing of each group of fish as they moved up the river in 1991.

upstream dams with well defined peaks 3-5 d apart (Figure 22). Fish in the fourth and last group moved upstream noticeably slower and few of the fish were counted at the upstream dams compared to the first three groups. Peak numbers of the first group (orange tag) were counted at Lower Monumental Dam 5 d after release, at LittleGoose Dam after 7 d,

and at Lower Granite Dam after 11 d. Similar timing was observed for the second and third groups released.

At Lower Monumental Dam, steelhead with the loop tags started passing and were recorded by the fish counters 2 d after the first releases from the first three tag groups (Figure 23). Steelhead in the fourth group were not counted at Lower Monumental Dam because counting was discontinued at the end of October, and fish for the first, second and third groups were counted for 46, 31, and 16 days, respectively. Despite the unequal number of counting days after release at Lower Monumental Dam for the first three groups of tagged steelhead, the data can be analyzed because most of the fish had passed the dam within 10 d of release (Figure 22). Mean and median days to pass Lower Monumental Dam and the percentage of fish released that were counted was based on the first 16 days of counting after release so the data would not be biased from the unequal periods of counting. The mean days to pass Lower Monumental Dam after release at Charbonneau Campground ranged from 5.1 to 5.7, and the median day of passage for all three groups was the fifth day (Table 5).

At Little Goose Dam, fish counters started recording the passage of fish from all four groups 3-4 d after their respective releases (Figure 23). The minimum period of counting for any group at Little Goose Dam was 33 d, so the mean and median days to pass, and the percentage counted at the dam was based on the first 33 d after each release. The mean days to pass Little Goose Dam ranged from 7.9 d for the second group to 13.0 d for the last group (Table 5). The median day of passage ranged from day 7 to 12.

Spaghetti-tagged steelhead began passing Lower Granite Dam 5 or 6 d after their respective releases (Figure 23). Counting of fish at Lower Granite Dam continued into December and the last group released was counted for 47 d, so estimates of mean and median days to pass and percentages counted were based on the first 47 d after each group was released. Mean days to pass Lower Granite Dam ranged from 10.6 for the second group to 20.1 for the fourth group (Table 5). The median day of passage ranged from day 10 to 18.

The cumulative frequency distributions of fish passing each dam versus days after release illustrate some of the migration differences between the four groups of fish (Figure 24). The cumulative distributions for the three groups counted at Lower Monumental Dam appear similar. At Little Goose Dam, the cumulative passage patterns of groups one and three (orange and yellow tags) are similar, but group two (green tags) appears to have migrated faster and group four (blue tags) slower than the other groups.

Table 5. Mean and median days to pass the three Snake River dams upstream from Ice Harbor Dam and percentage of fish released that were counted, based on counts of tagged steelhead passing the counting window for the four groups of spaghetti-loop tagged steelhead released for the zero-flow study. Estimates based on 16 d of counting after release for Lower Monumental Dam, 33 d at Little Goose Dam, and 47 d at Lower Granite Dam.

Group Release dates Tag color	Flow at night	Lower Monumental Dam			Little Goose Dam			Lower Granite Dam		
		Mean (d)	Median (d)	Percent	Mean (d)	Median (d)	Percent	Mean (d)	Median (d)	Percent
Group 1 16-20 Sep Orange	Zero	5.4	5	86.0	9.0	8	84.9	12.2	11	83.7
Group 2 30 Sep-4 Oct Green	Normal	5.1	5	79.5	7.9	7	79.5	10.6	10	75.7
Group 3 14-18 Oct Yellow	Zero	5.7	5	76.5	9.0	8	75.0	14.6	11	66.8
Group 4 28 Oct-2 Nov Blue	Normal	---	---	---	13.0	12	57.6	20.1	18	47.4

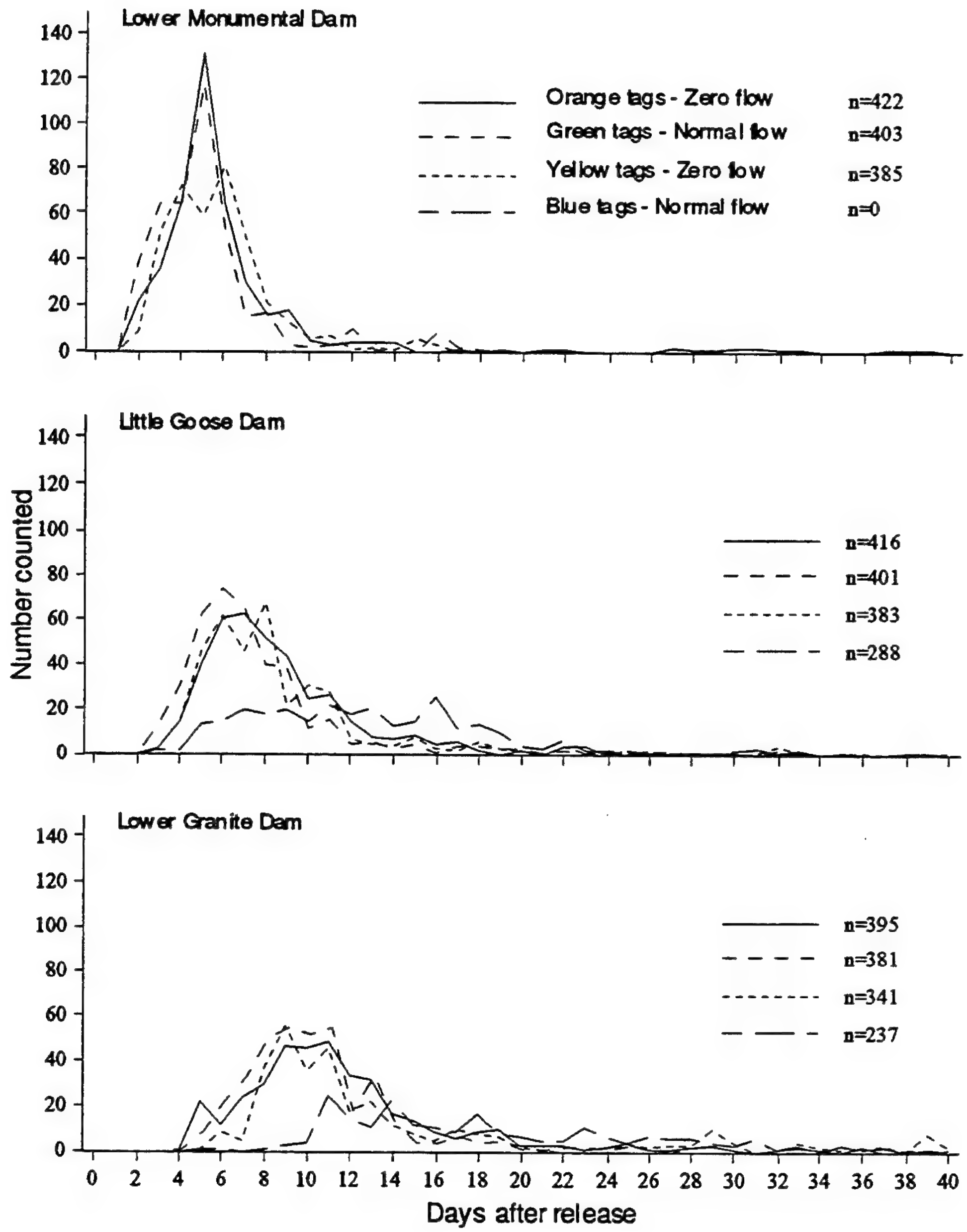

Figure 23. Frequency distribution of steelhead with spaghetti-loop tags that were counted at the three upper Snake River dams to illustrate the timing at each dam following the release of each groups of fish.

In our preliminary statistical analyses, some of the mean days to pass and cumulative distributions are statistically different. The differences between group four (blue tags) and the other groups are obvious and biologically significant, but probably not the result of

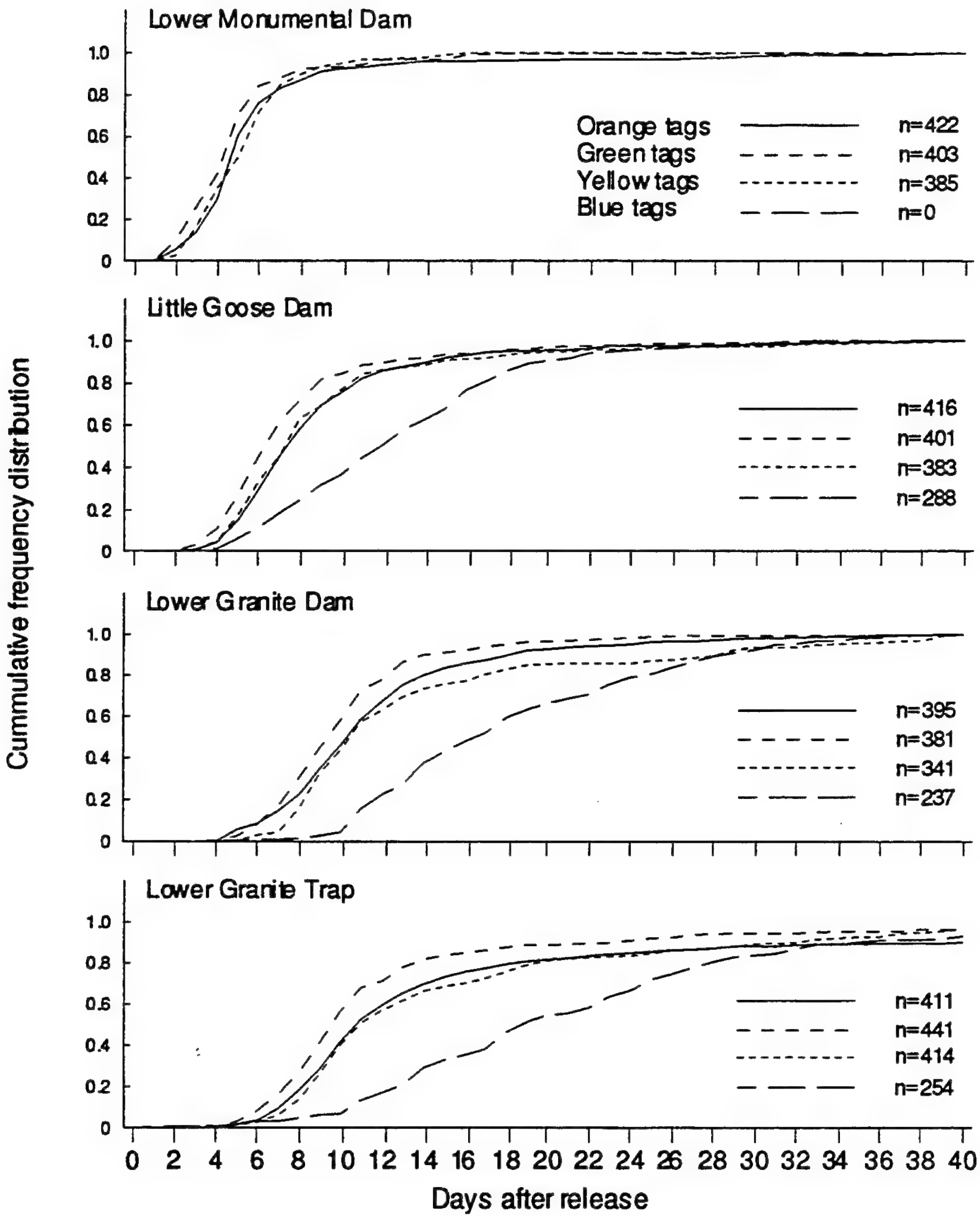

Figure 24. Cumulative frequency distribution of steelhead of each of the four groups tagged with spaghetti-loop tags, counted at the three upper Snake River dams, and recaptured in the Lower Granite adult trap in 1991.

discharges at night from the dams. Some of the differences between the first three groups may be statistically significant, but may not be due to nighttime discharges and may not be

significant biologically. River temperature declined steadily during the zero-flow study, as we expected, and may have been more of a factor in migration rates and behavior than other factors. In 1992, the order of periods with zero versus normal flow at night will be reversed from 1991 to determine if fish that enter the Snake River when temperatures are beginning to decline migrate at a slower rate than fish migrating two to four weeks later. In addition, the collection and analysis of data from fish taken in the fisheries and returning to hatcheries must be completed before a full picture can be developed for fish tagged in 1991.

The percentage of the fish released that were counted at the three dams is based on the minimum number of counting days for each dam as described earlier. The number of tagged steelhead from the three groups counted at Lower Monumental Dam amounted to 86% of the first group down to 76.5% of the third group (Table 5). At Little Goose Dam, the number counted was 84.9% of the first group and declined to 57.6% of the fourth group. At Lower Granite Dam, the counts amounted to 83.7% of the fish released in the first group and declined to 47.4% of the fourth group. The percentages of fish of each group counted have not been corrected for fallback that may have occurred at the dams or for fish destined to enter the Tucannon River or Lyons Ferry Hatchery. In the spring of 1992, some fish from all four groups have been counted at Lower Granite Dam, but the last group with the blue tags have been the most numerous.

Fish recaptured at Lower Granite Dam.-Recaptures of fish with spaghetti-loop tags at the adult trap at Lower Granite Dam had the same patterns in terms of timing of recaptures as the counts of tagged fish in the fishways. Fish in the first group (orange tags) released at Charbonneau Campground starting on 16 September began showing up at the Lower Granite trap 5 d later on 21 September, with the mode and median day of passage on the 10th day after release, and the mean at 14.0 d (Figure 25, Table 6). The peak number of recaptures (mode) was the same for the first three groups at 10 d, but was 14 and 18 d for the fourth group. The last group was available for recapture for 50 d and so that was the period of trapping used to calculate the median and mean days to recapture. The median days to recapture at Lower Granite Dam ranged from the 9th for the second group to the 18th for the fourth group. The mean days till recapture at Lower Granite Dam was lowest for the second group (12.1 d) and highest for the fourth group (21.6 d).

From preliminary analysis of the recapture data, the mean days to recapture at the dam for groups two and four (green and blue tags), that migrated during normal flow at

night periods, were significantly different from the means for groups one and three. The same was true for the cumulative distribution of counts of tagged fish at the dams (Figure 24). Fish in the second group migrated faster than fish in groups one and three, but fish in the fourth group migrated slower. Because temperature was declining throughout the four periods of the zero-flow test, and because of the inconsistent response, we are not sure the statistical differences were caused by the nighttime discharges from the dams.

The percentage of each group of fish released for the zero-flow test that were recaptured at the Lower Granite adult trap ranged from a high of 86.3% for the second group (green tags) to 50.8% for the fourth group (Table 6). These percentages are for the first 50 d of trapping after release of the respective groups, and they have not been corrected for any fallback that may have occurred at the dams or loss of tags, which was minimal.

Table 6. Mode, median, and mean days till recapture of steelhead at the Lower Granite adult trap that were tagged with spaghetti-loop tags and released at Charbonneau Campground during the zero-flow test in 1991. Data used was for the first 50 d after release of each group.

Group number Release dates tag color (number released)	Flow at night	Statistics for recaptures at adult trap (days after release) Mode	Median	Mean	Percent recaptured
Group 1 16-20 Sep Orange (471)	Zero	10	10	14.0	82.0
Group 2 30 Sep-4 Oct Green (502)	Normal	10	9	12.1	86.3
Group 3 14-18 Oct Yellow (503)	Zero	10	11	15.4	81.5
Group 4 28 Oct-2 Nov Blue (500)	Normal	14	18	21.6	50.8

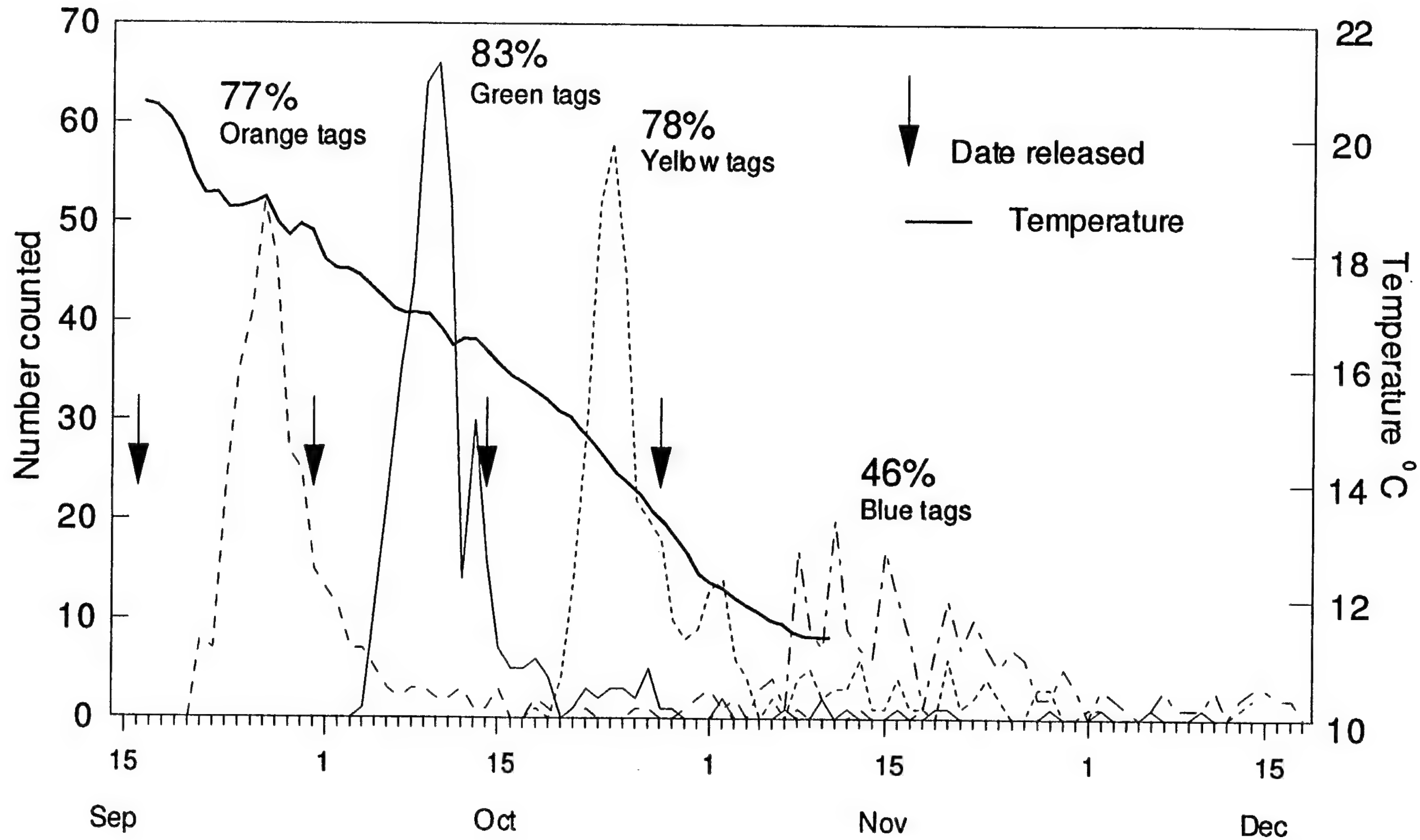

Figure 25. Timing of recaptured steelhead with spaghetti tags at the Lower Granite adult trap. Counts are presented separately for each of the groups released during the zero flow tests. Water temperatures are presented to illustrate the effect of low water temperatures on the time of arrival at the trap.

Water Temperatures at the Dams

During 1991, electronic temperature recorders were installed and maintained at the top of a fishway, at the lower end of the fishway (upstream from the supplemental flow inlets), and in the tailrace at each of the Snake River dams during the summer and fall. Water temperatures reached a peak of 23-25^{o}C in mid August in the lower Snake River (Figures 26-28). The discharge from the turbines (tailrace) was often 1-3^{o}C cooler than water at the top of the fishway or at the lower end, upstream from the supplemental water inlets. The water warmed as it moved from the top to the bottom of the Ice Harbor south-shore fishway during the hot sunny days of summer and fall.

The cool water releases from Dworshak Dam in August and September had a measurable effect on the tailrace temperatures at Lower Granite Dam in late August and perhaps in early to mid September (Figure 26). A similar reduction in the temperature of water discharged from the turbines was not evident at Ice Harbor Dam (Figure 27). Steelhead delayed entering the Snake River in large numbers until mid September in 1991, when temperatures had declined to about 20^{o}C in the tailrace.

Discussion

Conditions for upstream migration of adult spring and summer chinook salmon in the lower Snake River were favorable in 1991 because of the low flows, lack of spill, and low turbidities during most of the spring and early summer. The migration rates observed in 1991 were near the high end of the range observed in past studies (Bjornn and Perry 1992) and probably represent the rates that can be expected under conditions that are favorable for upstream migrants. In years with higher spring runoffs, spill at the dams, and more turbid water, the fish may not pass through the lower Snake River as quickly as in 1991. In 1981 for example, Turner et al. (1983) reported that chinook salmon took nearly 8 d to pass Lower Granite Dam when spill exceeded 25 kcfs versus only 2 d when there was less spill. In 1991, the mean time for chinook salmon to pass Lower Granite Dam was 3.1 d and there was no spill.

The mean time of nearly 8 d for spring and summer chinook salmon to pass Ice Harbor Dam was about four times longer than at Lower Monumental and Little Goose dams in 1991. Operation of the fish trap in the south ladder and forcing the tagged fish to pass the dam a second time may have contributed to the delay. During the steelhead migration season, we released some tagged steelhead upstream from Ice Harbor Dam as

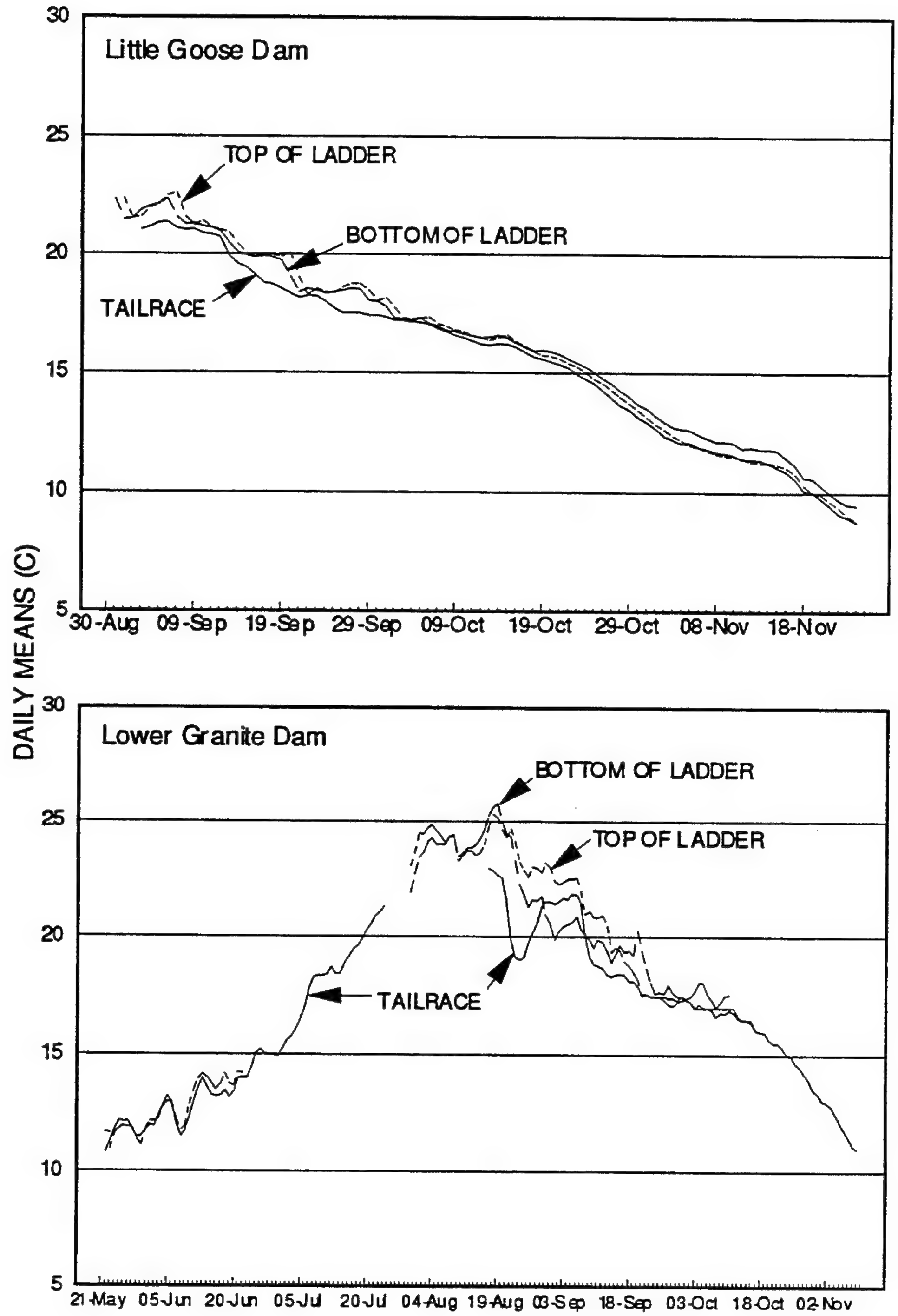

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Figure 26. Mean daily water temperatures at Lower Granite and Little Goose dams in 1991 during the summer and fall. Temperatures were recorded in the top pool of the south-shore fishways, near the lower end of the fishway upstream from the supplemental flow inlets supplying water from the tailrace, and in the tailrace downstream from the turbine discharges.

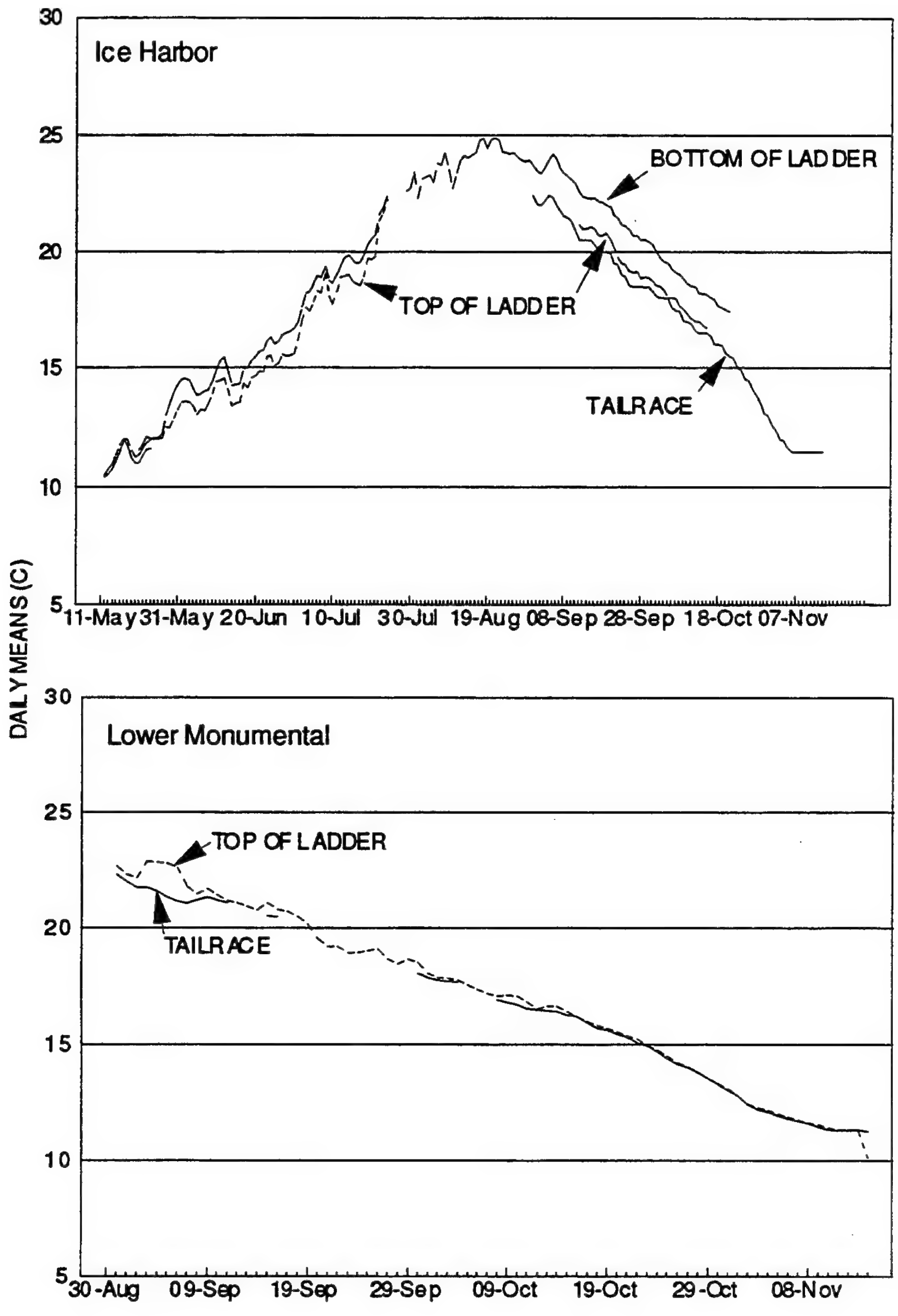

Figure 27. Mean daily water temperatures at Lower Monumental and Ice Harbor dams in 1991 during the summer and fall. Temperatures were recorded in the top pool of the powerhouse fishways, near the lower end of the fishway upstream from the supplemental flow inlets supplying water from the tailrace, and in the tailrace downstream from the turbine discharges.

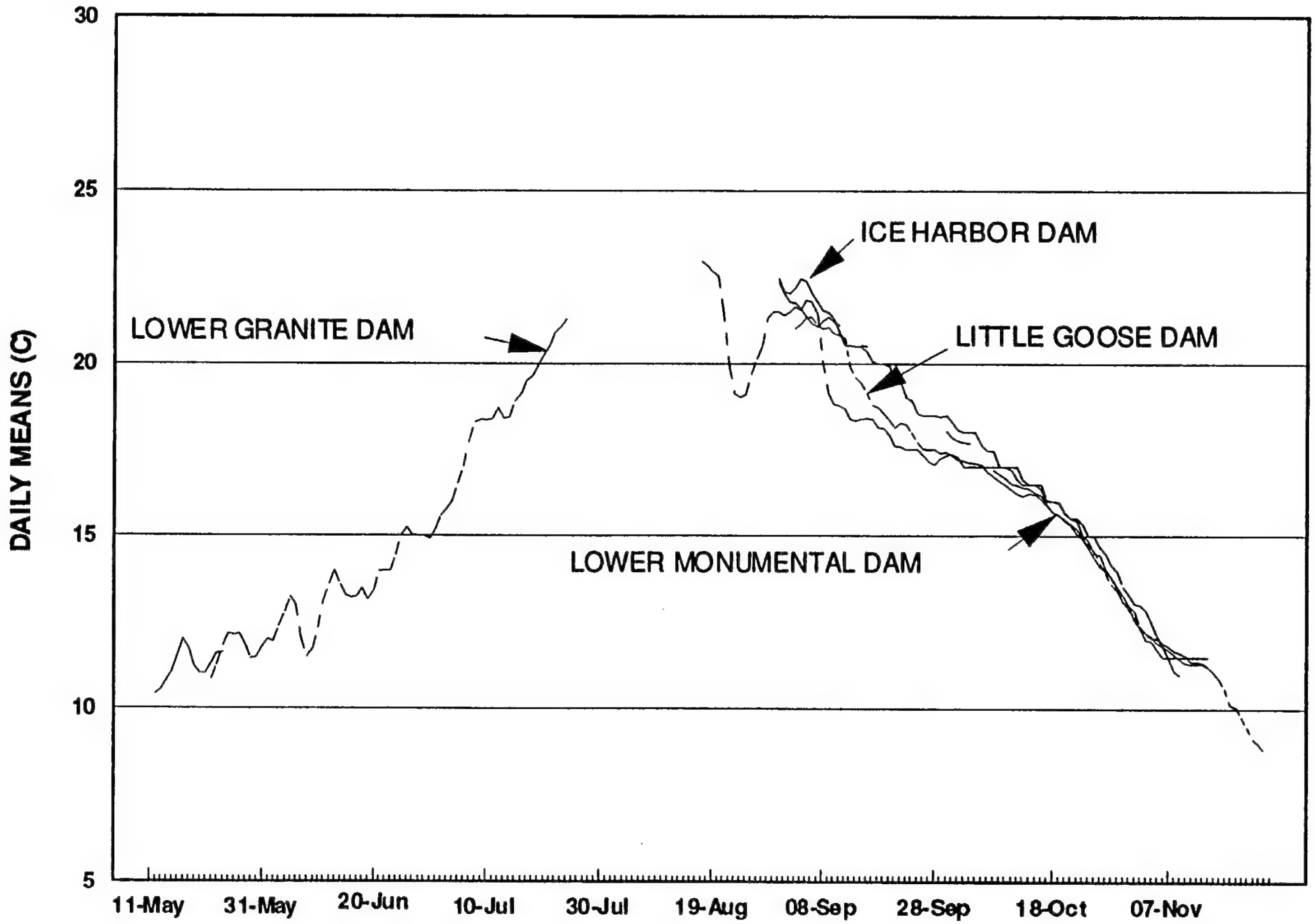

Figure 28. Mean daily water temperatures in the tailrace at the four lower Snake River dams in 1991 during the summer and fall.

well as downstream at Hood Park to see if there were differences in migrations caused by release location. We also increased the monitoring of steelhead in 1991 and chinook salmon in 1992 with transmitters while they migrated up the south fishway to determine if the delay occurred in the fishway. Data from the alternate release sites and increased monitoring are being analyzed.

Migration rates of chinook salmon through the Snake River reservoirs (about 55 km/d) and in free-flowing rivers upstream from the dams (16-31km/d) in 1991 were similar to those observed in prior years (Turner et al. 1983, 1984; Oregon Fish Commission 1960). We will attempt to correlate migration rates of individual fish with turbidity in the reservoirs and rivers where we can obtain such information.

Success of passage of spring and summer chinook salmon from Ice Harbor to Lower Granite dams in 1991 was 87%, a rate similar to that observed from an analysis of counts at the two dams from 1975 to 1989 (Bjornn 1990). For the full dam and reservoir complex in the lower Snake River (tailrace at Ice Harbor to Lewiston), at least 75% of the salmon with transmitters passed successfully. In our first attempt at trying to determine which salmon with transmitters reached the spawning grounds and hatcheries, we estimated that about 55% of the fish were successful. In a separate effort, Bjornn (1990) estimated that 45 to 55% of the wild chinook salmon passing Ice Harbor Dam survived to spawn during the 1962 to 1989 period.

Based on the time of capture at Ice Harbor Dam, we were able use the fish with transmitters to increase the information available on the distribution of spring versus summer chinook salmon in the Snake River basin. The distinction between spring and summer chinook salmon begins with their time of entry into the Columbia River and passage over Bonneville Dam. The separation in timing usually continues as the fish migrate up the river, especially in years like 1991 with relatively clear flows. In 1991, there was a nadir in the counts of chinook salmon at Ice Harbor Dam in late May that coincided with the normal division between spring and summer chinook salmon and a batch of turbid water that passed through the system. In general, we believe the fish we tagged and released in April and May were likely spring chinook salmon and those tagged and released in June and July were likely summer chinook salmon. However, keep in mind when looking at the data, the possibilities that an early migrating summer chinook salmon may have reached Ice Harbor Dam by mid May, or that a delayed spring chinook salmon may not have made it to Ice Harbor Dam until June. The distribution of salmon in 1991 varied by drainage and hatchery with some having entirely spring or summer chinook salmon and some areas a mixture of both. As additional years of data are added to that

collected in 1991, we will have a clearer understanding of the fish that make up the stocks in each spawning area and hatchery.

In 1991, spring and summer chinook salmon with transmitters distributed themselves into the Clearwater (25%), Grande Ronde (9%), Imnaha (4%), and Salmon (62%) river drainages unevenly, but probably related to the amount of natural production areas available and hatchery production. The fact that transmitters were placed in larger fish (large two year in ocean and three year in ocean fish) may have distorted the distribution by drainage. In 1992 and future years, the use of smaller transmitters will eliminate that potential bias.

Because many of the tagged steelhead were still migrating when this report was prepared, we cannot provide the migration rate and distribution data as we have for chinook salmon. The distribution of tagged steelhead recaptured in the fisheries, that we have processed through 12 May 1992, includes fish that moved back downstream after release near Ice Harbor and were caught in the Columbia (21) or Walla Walla (10) rivers, 226 caught from the Snake River from the mouth to Lewiston, 11 fish caught in the Tucannon River, and 442 fish from the Snake River and its tributaries upstream from Lewiston. We do not expect the distribution of harvested fish to change much as the last of the reports of recapture are received.

The preliminary results from the test to assess the effects of reducing discharge from the three upper dams to near zero at night during the fall on the migration of steelhead provided mixed results. The first of four two-week test periods began in mid September when river temperatures had declined and adequate numbers of steelhead were moving into the Snake River. The first period was a zero flow period followed by one with normal flow, then one with zero flow, and finally the last one with normal flow. In general, migration rates and the percentage counted or recaptured at the upstream dams was highest for the steelhead released at the start of the second period with normal flow at night. Steelhead released in the first and third periods with zero flow at night migrated at similar rates that were almost as fast as the fish in the second period. Steelhead in the fourth period migrated much slower than fish in the earlier period, despite having normal flow at night. Although the differences in migration rate are significant between fish in the first and third versus second and fourth periods, we are not sure the differences are a result of flow at night. River temperatures were declining throughout the duration of the test and may have been the major factor in setting migration rates. We could theorize that during the first period temperatures were still too high for maximum migration rates, during the second period temperatures and season were ideal for rapid upstream movement, by

the third period temperatures and time of season were starting to exert a drag on migration, and by the fourth period many fish were entering the overwintering behavior pattern of holding somewhere in the lower Snake River. Additional tests will help clarify the role of temperature versus flow at night in migration rates of steelhead.

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ADULT SALMON USE AT FISHWAY ENTRANCES BASED ON ELECTRONIC TUNNELS AND EVALUATION OF THE FISHWAY FENCES AT LITTLE GOOSE AND LOWER GRANITE DAMS - 1991

by

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SUMMARY

Objectives for 1991

During 1991 we planned to (1) determine the effects of quantity and pattern of spill on use of fishway entrances by adult salmon and steelhead at Little Goose and Lower Granite dams, (2) evaluate the effectiveness of "fallout fences" installed in fishways near north powerhouse entrances 1 and 2 at both dams in reducing numbers of adult salmon and steelhead that fallout through those entrances, and (3) assess use and fallout through fishway entrances under various conditions of flow and powerhouse operation.

Accomplishments in 1991

Low spring flow in the Snake River precluded evaluation of spill patterns at Little Goose and Lower Granite dams (Objective 1). However, we accomplished Objectives 2 and 3. In addition, we expanded Objective 3 to include an evaluation of use and fallout through all entrances when we varied the combination of north powerhouse entrances that were open. Because only two of the three north powerhouse entrances could be open at the same time to maintain the fishway within criteria, this evaluation enabled us to identify the combination of two north powerhouse entrances that maximized use of and minimized fallout through each one.

Findings in 1991

The "fallout fences" did not appear to prevent or reduce fallout of adult salmon or steelhead through north powerhouse entrances 1 and 2 at Little Goose or Lower Granite dams. At Little Goose Dam, the south shore entrance was the most used, although its use appeared to vary with changes in powerhouse operation. At Lower Granite Dam, the north shore entrance was most used; there was no apparent relationship between its use and changes in powerhouse operation. In general, the floating orifice gates received little use and had very low levels of fallout. We found that north powerhouse entrances 1 and 2 at both dams received little use and had relatively high levels of fallout. Use of north powerhouse entrance 3 appeared to be greatest during the fall at both dams.

INTRODUCTION

Background

Adult salmon and steelhead migrating to their natal streams in the Snake River Basin must pass eight dams and reservoirs, four each in the lower Columbia and Snake rivers. The Columbia River watershed historically produced more chinook salmon (*Oncorhynchus tsawytscha*) than any other river system in the world, with a majority of some stocks coming from the Snake River Basin (Fulton, 1968; Netboy, 1980; Williams, 1989). However, stocks of Snake River salmon and sockeye (*O. nerka*) have recently become so depleted (United States Army Corps of Engineers, Annual Fish Passage Report, 1990) that they have been listed as threatened and endangered, respectively. Passage efficiency and

effectiveness must be optimized to reduce salmon losses and delays at each dam. This study was developed in response to the high priority assigned to adult passage research in the Snake River by the U.S. Army Corps of Engineers through the Fish Research Needs and Priorities subcommittee of the Fish Passage Development and Evaluation Program.

This study is identified in, and supported by, the Northwest Power Planning Council's 1987 Columbia River Basin Fish and Wildlife Program which states that the Corps of Engineers shall conduct studies to determine the effects of reduced and instantaneous flows on adult fish. The need to evaluate spill criteria, which was developed 25 years ago under less-than-ideal conditions, has been recognized. Also included in the Program is the need to study flows at fishway entrances to determine the best flows and operation conditions for enhancing adult passage.

Research has been conducted in the past by various agencies to evaluate use of and fallout through fishway entrances by adult salmonids (Johnson et al. 1979, 1982; Turner et al. 1983, 1984). However, additional studies were needed to better define use and fallout from fishways because studies at the Lower Snake River dams were conducted during only a part of the migration season and with an incomplete range of flow conditions. Following recommendations made by Turner (1983), fishways were modified at Little Goose and Lower Granite dams in Winter 1991 in an effort to reduce fallout; these modifications needed to be evaluated.

In the two-year study at Lower Granite and Little Goose dams, objectives for 1991 were to (1) assess use of and fallout through fishway entrances at these dams under various conditions of flow and powerhouse operation, (2) evaluate the effectiveness of "fallout fences" installed in fishways near north powerhouse entrances 1 and 2 at both dams in reducing numbers of adult salmon and steelhead that fallout through those entrances, and (3) determine the effects of quantity and pattern of spill on use of fishway entrances by adult salmon and steelhead.

Low spring flow in the Snake River precluded evaluation of spill patterns at Little Goose and Lower Granite dams (Objective 3). However, we initiated Objectives 1 and 2 in this first year. In addition, we expanded Objective 1 to include an evaluation of entrance use and fallout through all entrances when we varied the combination of north powerhouse entrances that were open. Because only two of the three north powerhouse entrances could be open at the same time and still maintain the fishway within criteria, this evaluation enabled us to identify the combination of two north powerhouse entrances that maximized use of and minimized fallout through each one. We felt this task belonged under Objective 1 because fishway operations could also affect use and fallout.

The focus of this progress report is to cursorily examine relationships between powerhouse and fishway operations and use of and fallout through fishway entrances by adult chinook salmon and steelhead. Future progress reports will quantitatively and statistically assess these relationships.

Study Site

Little Goose and Lower Granite dams are located on the Snake River in eastern Washington at River Miles 70.3 and 107.5, respectively. Each project includes a 656-foot long powerhouse containing six generator units, a spillway with eight spillbays, a juvenile fish collection facility, and a navigation lock (Figures 1 and 2).

Little Goose Dam

The adult fish collection system at Little Goose Dam consists of a continuous channel under the spillway and along the powerhouse. Fish can enter the collection system through entrances located (1) at the north end of the spillway (NSE-1 and NSE-2), (2) at the north end of the powerhouse (NPE-1, NPE-2, and NPE-3), (3) at the face of the powerhouse (FOG-1, FOG-4, FOG-6, and FOG-10), and (4) at the south end of the powerhouse (SSE-1 and SSE-2). NSE-1 and NSE-2 are 6-foot wide slots with overflow weirs submerged six feet (submergences are expressed in relation to tailwater). NSE-1 and NSE-2 are oriented downstream and open to a 17.5-foot wide lighted tunnel that passes through the spillway to the north end of the powerhouse. NPE-1 and NPE-2 are 6 feet wide with 6-foot deep overflow weirs and are oriented downstream; NPE-2 is the southernmost north powerhouse entrance. NPE-3 is a 6-foot wide entrance (with no overflow weir) oriented toward the spill basin and is the northernmost powerhouse entrance. FOGs are floating orifice gates that adjust automatically to fluctuations in tailwater elevation to maintain a 2- by 6-foot opening submerged approximately four feet below tailwater. SSE-1 and SSE-2 are 4 feet wide with overflow weirs submerged six feet. SSE-1 and SSE-2 are adjacent entrances oriented northward and opening to a 17.5-foot wide channel that connects to the main collection channel near the base of the fish ladder on the south shore (Figure 1). The fish ladder is 16 feet wide with a 1 on 10 slope and an 8 foot water depth, rising approximately 100 vertical feet. Auxiliary water is supplied to the collection system by three turbine-driven pumps. Auxiliary water supply pump intakes are located near the south shore entrances

Lower Granite Dam

The adult fish collection system at Lower Granite Dam is similar in design and operation to that of Little Goose Dam. Differences are that fish enter at the face of the powerhouse through FOG-1, FOG-4, FOG-7, and FOG-10. NSE-1 and NSE-2 are 6-foot wide slots with overflow weirs submerged 8 feet. NPE-1 and NPE-2 are 6-feet wide with 8-foot deep overflow weirs; NPE-1 is the southernmost north powerhouse entrance. SSE-1 and SSE-2 are approximately 88 feet apart (Figure 2). An adult fish trapping facility is located about midway up the ladder at Lower Granite Dam. Auxiliary water is supplied to the collection system by three electric pumps with pump intakes located near the south shore entrances.

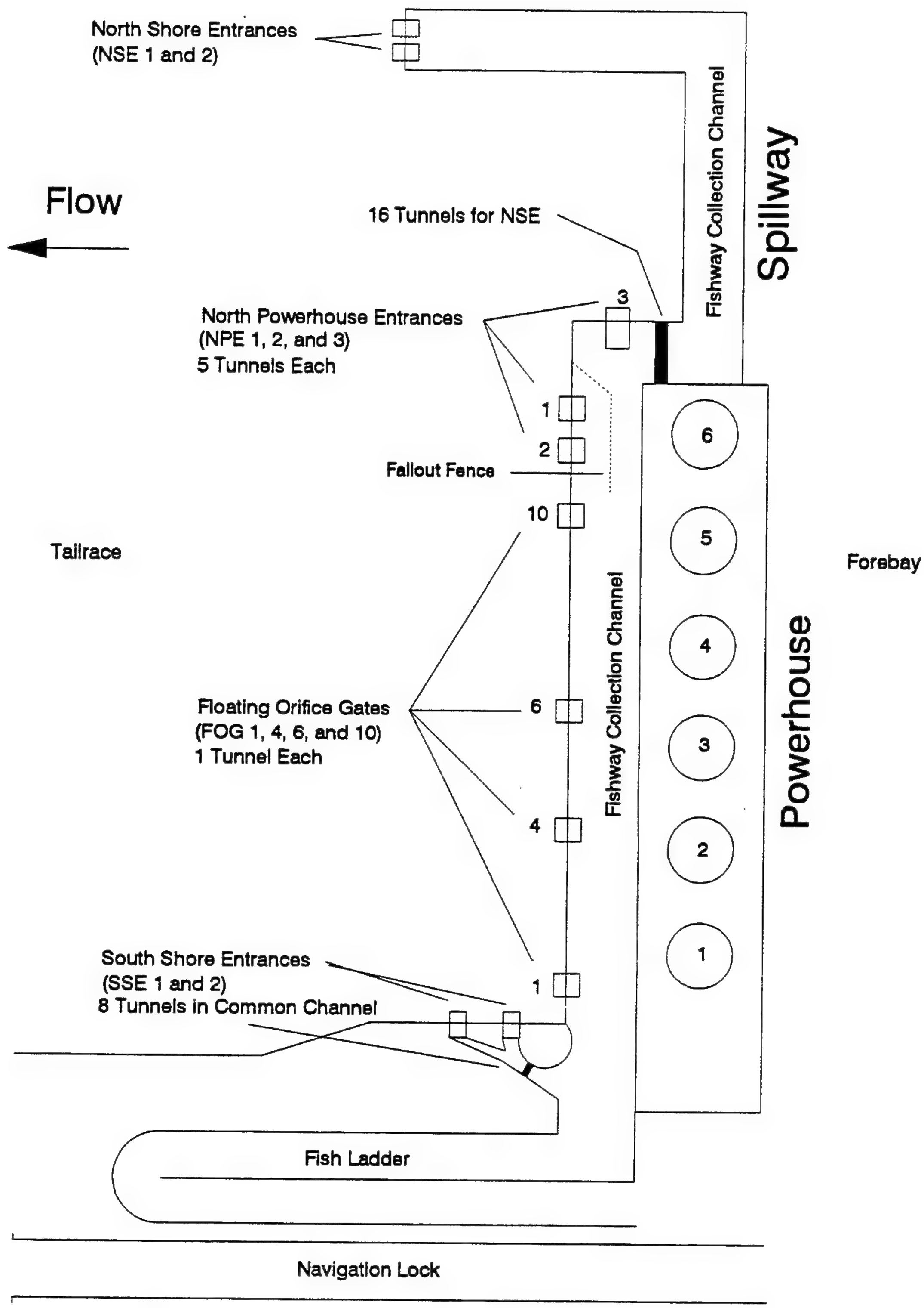

Figure 1. Location of fishway entrances, electronic tunnels, and "fallout fence" at Little Goose Dam, Snake River, 1991.

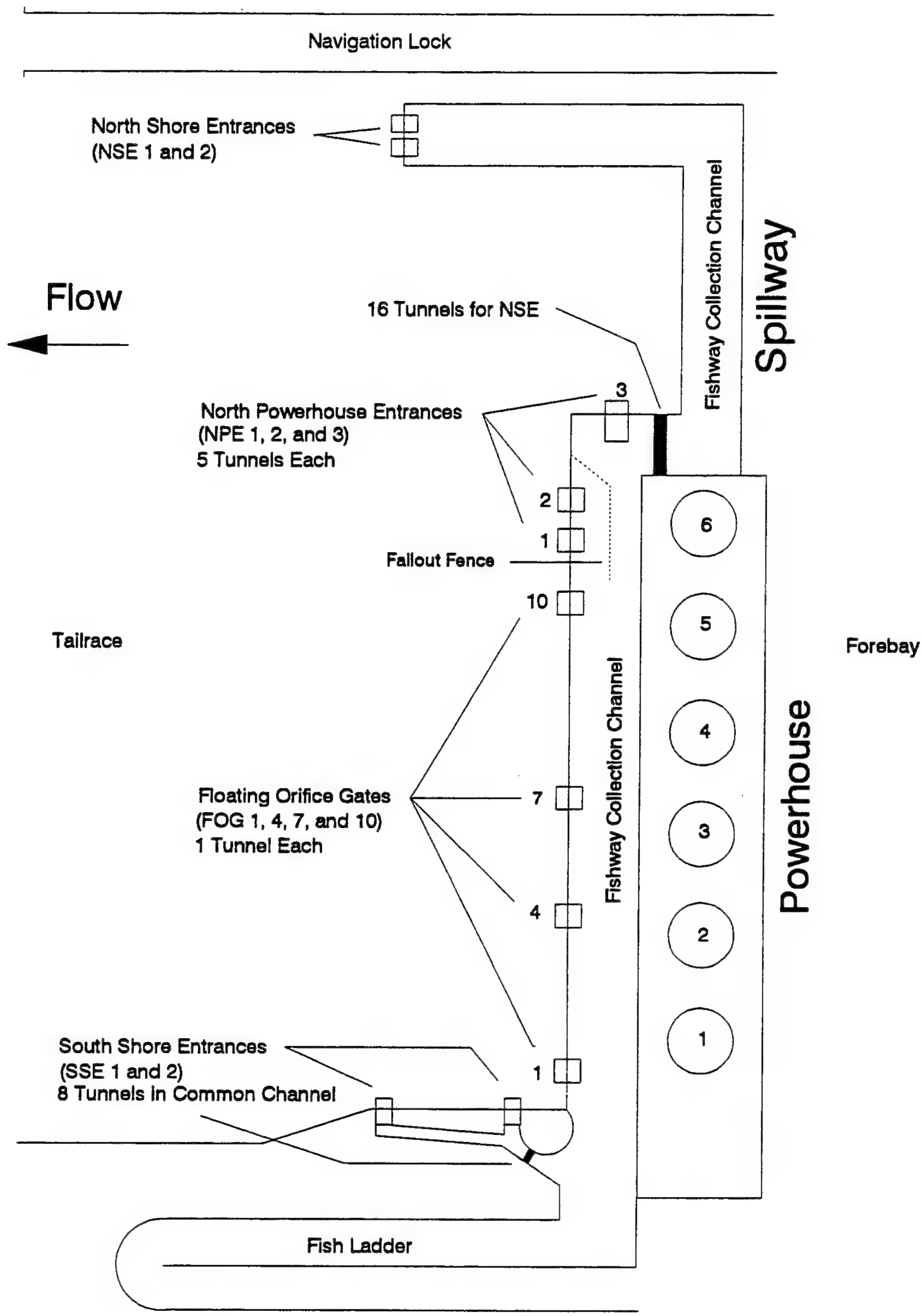

Figure 2. Location of fishway entrances, electronic tunnels, and "fallout fence" at Lower Granite Dam, Snake River, 1991.

METHODS

Equipment

Electronic balanced-bridge impedance tunnels were installed in most fishway entrances so that a fish must pass through them when entering or exiting the fishway. Electronic tunnels were also installed in the collection channel where entrance installation was not possible (NSE and SSE; fish movement through these tunnels did not completely reflect true fishway entrance or exit into the tailrace). We used two types of electronic balanced-bridge impedance tunnels. Center-electrode tunnels contained two electrode pairs placed in the center of the tunnel and were installed in the floating orifice gate entrances. Peripheral-electrode tunnels contained two electrode pairs placed peripherally at the top and bottom of the tunnel and were installed in the remaining entrances. Peripheral-electrode tunnels were fabricated from 3/4-inch marine grade plywood and were 3 feet deep with a 1.5-foot by 6-foot opening. Center-electrode tunnels, fabricated from 16-gauge perforated stainless steel, were 3 feet deep with a 2-foot by 6-foot opening. The two electrode pairs produced separate low voltage currents in the upstream and downstream halves of the tunnels. To isolate the electrical fields in the tunnels between electrode pairs, we coated the tunnel surface with a non-conductive electrical insulating paint.

Each tunnel electrode pair was wired to a corresponding electronic fish detector (Smith Root, Model 602-A) via coaxial cable (Figure 3). A detector contained resistive and capacitive integrated circuitry that, along with the resistance of the water between an electrode pair, made up four arms of a balanced bridge (Liscom and Volz 1974). Each detector was wired to a Model AL-600 Smith Root Inc. alarm unit. When a detector bridge became unbalanced for several seconds, an alarm unit would sense the imbalance and an audio or visual alarm was activated.

Because the body of a fish has a lower resistance to the alternating current than water, fish passing through a tunnel create an imbalance in the impedance bridge. A logic circuit in the fish counter senses the imbalance and, depending on the sequence of the upstream-downstream imbalances, records an "up" or "down" count on the tally register of the detector. To register an upstream or downstream count, the imbalances must occur within a 3-second interval of each other and been greater than the preset threshold level. We determined a near appropriate bridge sensitivity for counting fish greater than 20-inches fork length by passing dead adult salmonids of various lengths through electronic tunnels and documenting the sensitivity setting (30 microamps) at which fish greater than 20 inches would be counted. The sensitivity setting was approximate due to the difference in body resistance, body density, and swimming characteristics of dead fish versus live fish.

We installed multiple tunnels in metal frames wherever more than one tunnel was required to adequately encompass and monitor passage through a fishway entrance. Tunnel frames were fabricated of welded channel iron, angle iron, and flat bar, and contained galleries and clasps for protecting and securing the coaxial cable. We used PVC-coated chain-link fencing to prevent fish from passing over the top of the multiple tunnel configuration. At fishway entrances where multiple tunnels were present, fish detectors were wired to a master oscillator. The master oscillator set the alternating

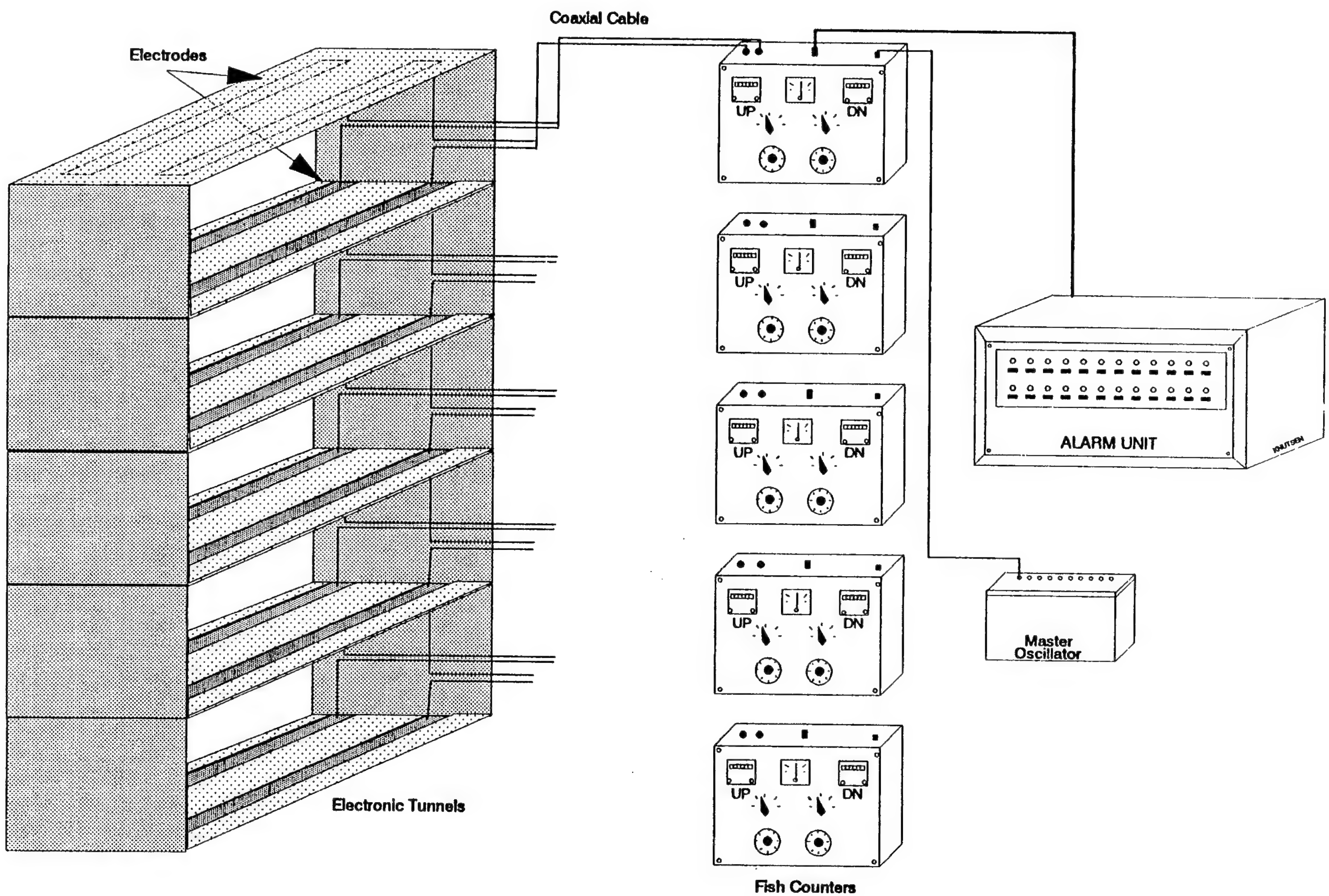

Figure 3. Schematic of the electronic fish detection system including electronic impedance tunnels, fish counters, alarm units, and master oscillators.

current for each tunnel in phase (1 khz), which minimized interference between adjacent tunnels.

At each dam we installed eight tunnels in the common channel upstream of SSE-1 and SSE-2, one center-electrode tunnel in each FOG, five tunnels each in NPE-1, NPE-2, and NPE-3, and 16 tunnels in the collection channel south of NSE-1 and NSE-2 (*see* Figures 1 and 2). Initially, we installed tunnels in NPE-3 by securing angle iron to the entrance walls and bolting the tunnel pieces into place. During the summer period, these tunnels malfunctioned and became damaged. We subsequently designed, fabricated, and installed a more structurally sound tunnel frame. Preseason installation and inseason inspection of all tunnel assemblies required crane service and assistance from Corps of Engineer (COE) project personnel.

As a result of research conducted at Little Goose and Lower Granite dams in 1981, it was recommended that the fishway at NPE-1 and NPE-2 be modified to reduce fallout through those entrances. COE personnel fabricated and installed a "fallout fence" that was designed to direct fish entering NSE-1, NSE-2, and NPE-3 around the outflow from NPE-1 and NPE-2. The fence was 16 feet high and constructed of 3-inch diameter metal piping and PVC-coated chain-link fencing.

Because only two of the three north powerhouse entrances could be opened at any one time and still maintain the fishway within criteria, we varied weekly the combination of those entrances that were open to determine the combination of two entrances that maximized use of and minimized fallout through each one. We randomly selected the pair of entrances that were open for any given week with each of three weekly combinations comprising a block. Crane service was provided weekly by COE project personnel to remove and replace NPE-1 and NPE-2 entrance bulkheads. A 1-ton electric hoist over the NPE-3 bulkhead was used to open and close that entrance.

As a precautionary measure, quality control procedures included a weekly rotation of fish counters to reduce possible biases associated with differential fish-counter performance. In addition, we routinely used a volt-ohm meter to detect possible breaks or shorts in the coaxial-tunnel circuit, and to measure and adjust counter sensitivity to maintain an effective bridge sensitivity. We attached a tunnel simulator to fish counters to simulate upstream and downstream passages of fish, which allowed us to determine if the counter registers were functioning properly.

Data Collection

Data were collected seven days per week during daylight hours from 24 April to 17 July and 11 September to 13 November. These periods corresponded to the times of expected peak migrations of spring and summer chinook salmon and summer steelhead, respectively. Cumulative upstream and downstream counts for each fish detector were recorded at one-hour intervals from 0700 to 2000 hours from 25 April through 15 July 1991, and from 0800 to 1700 hours from 11 September through 13 November 1991. We used upstream counts to gauge use and downstream counts to ascertain fallout. After we recorded counts, we cleared the registers and, if necessary, rebalanced the counters.

We assigned condition codes to all hourly electronic tunnel counts. Condition codes allowed us to determine, at a later date, which counts were reliable. Conditions necessary for a count to be considered reliable included, (1) the electronic tunnel remained in the water for the entire hour, (2) the counter remained in balance for at least 3/4 of the hour, and (3) interference from adjacent counters or other electronic equipment did not trigger multiple false counts during the hour.

To compare use and fallout with changes in powerhouse operations, we recorded at one-hour intervals project operation variables, including individual and total generator output (megawatts), forebay and tailwater elevations (feet), and fishway to tailwater elevation differential (feet). For purpose of analysis, we converted individual and total generator output from megawatts to thousands of cubic feet per second (kcfs) discharge. We also obtained daily counts of fish passing the fish viewing window from the fish counter.

Data Analysis

Tunnel and electronic fish counter malfunctions occasionally resulted in incomplete data sets. To estimate missing tunnel counts, we calculated a mean hourly count using all reliable counts from the affected tunnel recorded two hours before and two hours after the missing count. We assumed that if project operations changed within these two-hour periods, an immediate affect on fish passage would not be evident. If no reliable counts existed for the affected tunnel within the 2-hour range, we calculated a mean hourly count from adjacent tunnels, using counts recorded during the affected time period. If it was not possible to use either method, data was treated as missing and not considered for analysis.

We determined the proportion of tunnel counts per entrance that were estimated as:

$$\text{Total tunnel hours} \;/\; \text{estimated hours}$$

where

Total tunnel hours = tunnels/entrance x hours monitored/day x 7 days/week x no. of weeks, and

Estimated hours = sum of estimated hours for all tunnels per entrance.

To determine whether our tunnel counts reflected true passage by the projects, we compared numbers of fish using fishway entrances to numbers of fish passing the fish viewing window. We calculated daily net (NET) upstream passage through the tunnels:

$$NET = SUM\ UP - SUM\ DOWN$$

where

SUM UP = sum of all upstream counts for a set of entrances for a given day, and

SUM DOWN = sum of all downstream counts for a set of entrances for a given day.

We computed a correlation coefficient to determine if numbers of fish using fishway entrances were associated with numbers of fish passing the fish viewing window for two seasonal time periods, spring/summer and fall, corresponding to migration periods of adult chinook salmon (24 April - 17 July) and steelhead (11 September - 13 November). We used $P < 0.05$ as our level of significance.

"Fallout Fence" Effectiveness

To determine if the "fallout fence" was effective at reducing fallout through NPE-1 and NPE-2 (Objective 2), we calculated an index of fallout (TFALL) for each entrance during the spring period (24 April - 5 June) as described by Turner et al. 1983:

$$TFALL = DOWN/UP$$

where

DOWN = total downstream counts for a given entrance for a given time period, and

UP = total upstream counts for a given entrance for a given time period.

An index value > 1 represents more down than up counts, whereas an index value < 1 represents more up than down counts. We subjectively compared these values with those reported from 1981.

Entrance Use and Fallout

Because project operations often changed on an hourly basis, we used hourly counts to assess entrance use and fallout. To identify the entrances that were most used and where most fallout occurred and to determine if powerhouse and fishway operations affected use and fallout, we calculated use (USE) and fallout (FALL) as:

USE = total upstream counts for a given entrance for a given hour, and

FALL = total downstream counts for a given entrance for a given hour.

We grouped count data into two seasonal time periods, spring/summer and fall, corresponding to migration periods of adult chinook salmon (24 April - 17 July) and steelhead (11 September - 13 November). To identify entrance use and fallout for each migration period, we calculated mean USE and FALL for all fishway entrances by season.

We calculated mean USE and FALL for each combination of two north powerhouse entrances to determine the combination that maximized their use and minimized their fallout during each seasonal time period. We also calculated

mean USE and FALL for all entrances for each two-entrance combination to determine how each combination affected use and fallout at other entrances.

We calculated mean USE and FALL for each turbine operation pattern to determine if use and fallout were affected by changes in patterns during each seasonal time period. Each turbine operation pattern was a sequence of turbine units that were operated for at least one hour. Since some turbine operation patterns occurred for only a few hours during a period, we only calculated mean USE and FALL for those turbine operation patterns that occurred more than 5% of the time. Turbine units were usually brought online beginning with Unit 1 and progressing toward the north end of the powerhouse.

We computed a correlation coefficient to determine if USE and FALL were associated with total hourly discharge (kcfs).

RESULTS

Little Goose Dam

The proportion of tunnel counts that were estimated ranged from 29.7% (NPE-3) to 0.1% (FOG-6) during the spring/summer period and from 2.5% (NPE-2) to 0.1% (NPE-3) during the fall period. The majority of estimated hours per entrance was less than 0.6% of the total tunnel hours for both seasonal time periods.

The correlation between daily numbers of fish using fishway entrances and numbers of fish passing the fish viewing window was 0.41 and 0.88 ($P < 0.05$) for the periods 24 April - 17 July and 11 September - 13 November, respectively (Figure 4). Entrance use by non-salmonids was greater during the spring/summer period when large numbers were in the fishway. Non-salmonids passing the fish viewing window were not counted.

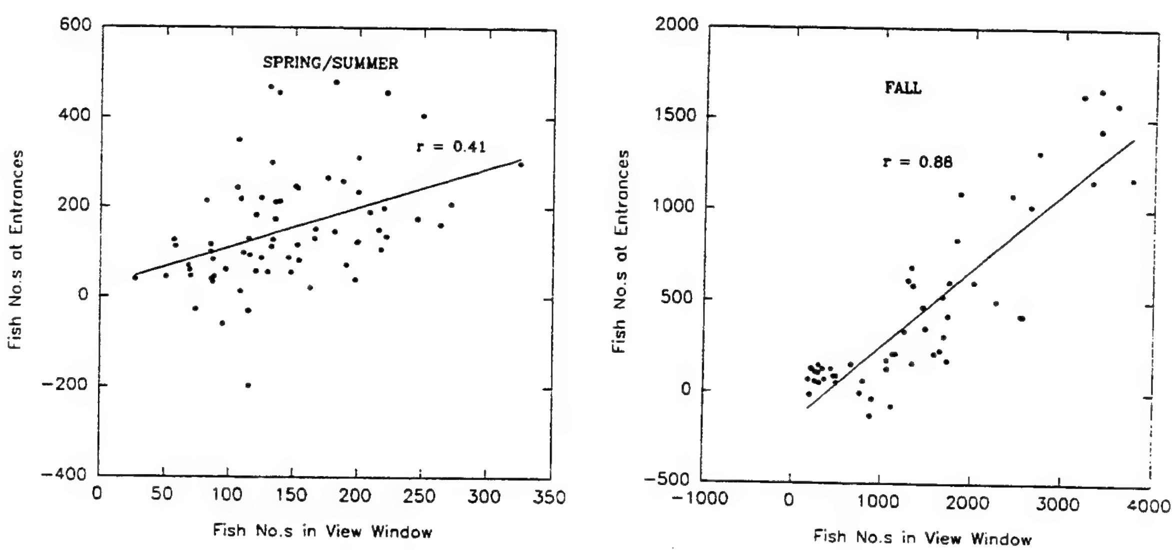

Figure 4. Correlation between daily numbers of fish using fishway entrances and numbers of fish passing the fish viewing window for the spring/summer and fall periods at Little Goose Dam, Snake River, 1991.

"Fallout Fence" Effectiveness

Fallout, as calculated by Turner et al. (1983), varied similarly among entrances between 1981 and 1991 with the exception of NSE (Figure 5). In 1981, fallout was lowest at NSE with down counts averaging only 12.5% of up counts. In contrast, down counts at NSE in 1991 totaled 88% of up counts. A difference in the tunnel configuration used at NSE between the two years is probably a major cause for this dissimilarity. During both years, fallout was highest at NPE-2. In 1991, a net loss of fish occurred through NPE-2, with down counts totaling 118% of up counts.

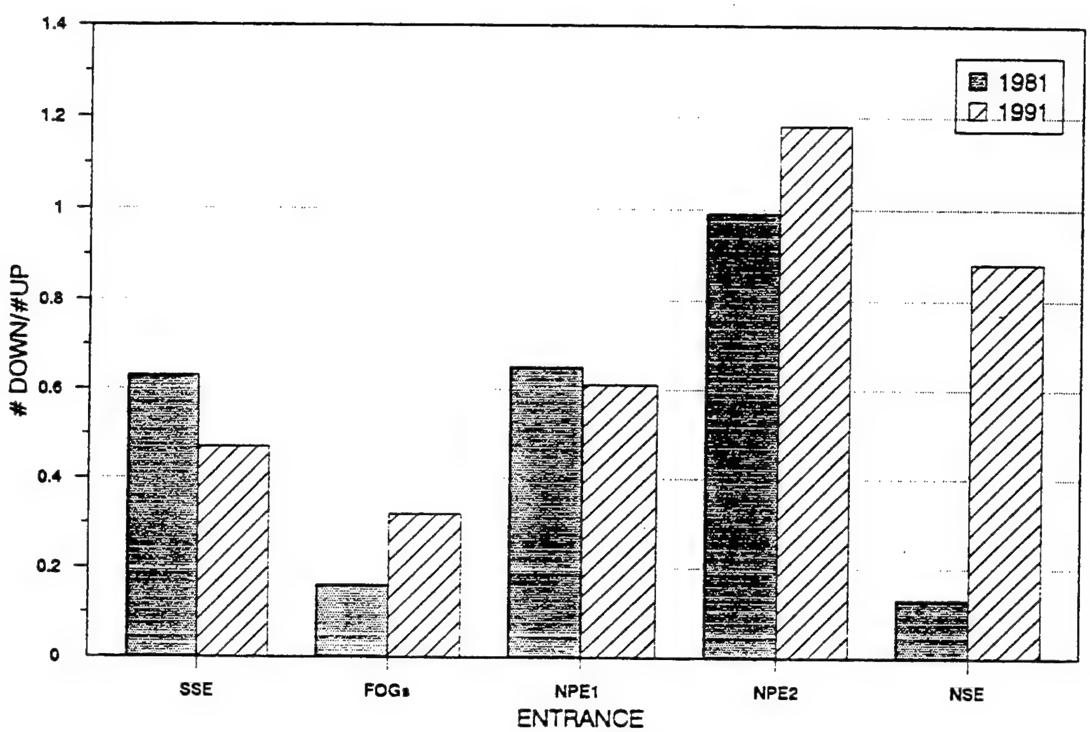

Figure 5. Fallout as calculated by Turner et al. (1983) for fishway entrances during spring 1981 and spring 1991 at Little Goose Dam.

Entrance Use and Fallout

The inability to distinguish fish species in tunnels somewhat confounds the interpretation of results relating to fish passage. This is particularly true for NSE and SSE, where non-salmonids are most likely to pass through the collection channel tunnels on a regular basis. During the spring/summer period, large numbers of non-salmonids were observed swimming in the fishway. This observation was verified during a mid-summer dewatering of the fishway which revealed thousands of carp present.

Patterns of entrance use were similar between seasonal time periods, and fallout was proportional to entrance use (Figure 6; Appendix A). Use and fallout were greatest at SSE during each time period. Fallout exceeded use at FOG-1 during the spring, at NPE-1 and NSE during the fall period, and at NPE-2

during both periods. In general, use was least at NPE-1, NPE-2, and FOGs during each period. Use of NPE-3 was considerably higher during the fall than during the spring/summer period. Tunnel malfunctions at NPE-3 during the spring/summer period resulted in a lower number of hourly observations for this entrance, although data was collected every week (Appendix A).

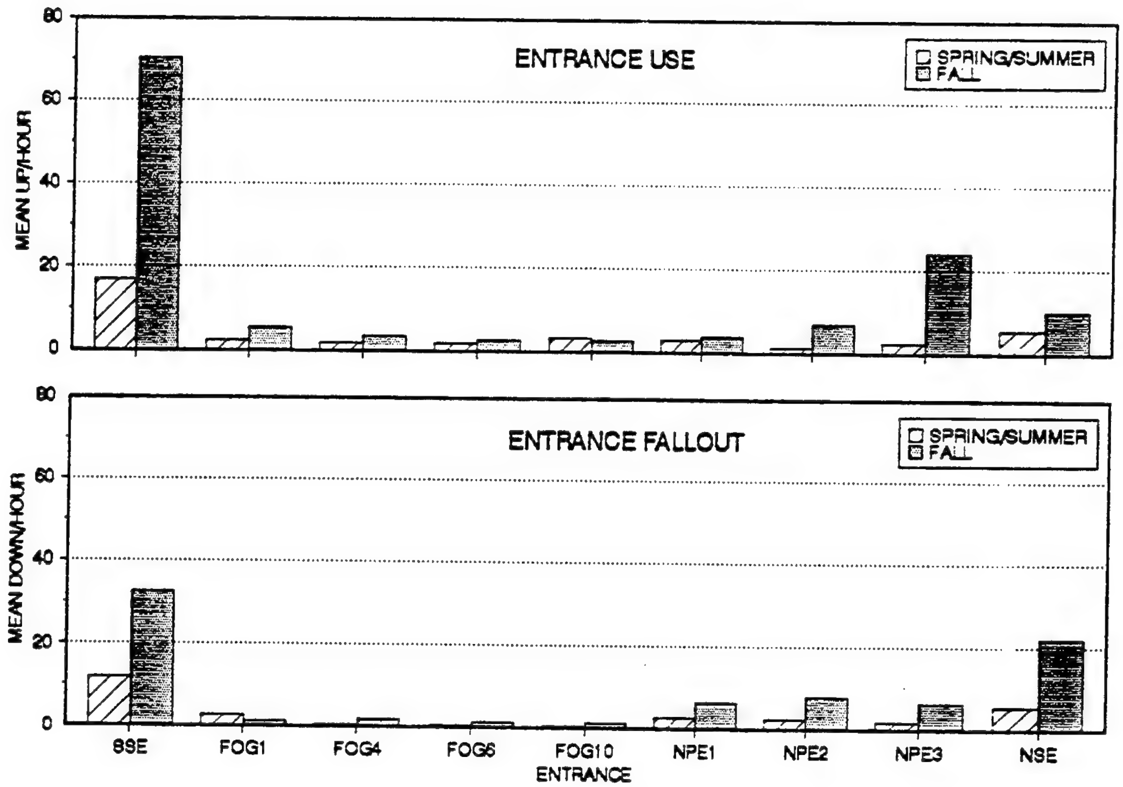

Figure 6. Mean hourly up counts and down counts at fishway entrances by seasonal time periods at Little Goose Dam, Snake River, 1991.

Little variation in entrance use and fallout was apparent among the combinations of NPEs that were open during the spring/summer (Figure 7; Appendix B), but some variation was apparent during the fall (Figure 8; Appendix B). Use and fallout at SSE were substantially higher during the fall when NPE-2 and NPE-3 were open than with the other combinations. In addition, NPE-3 received more use in combination with NPE-2 than with NPE-1.

Changes in entrance use and fallout with variations in turbine patterns were not consistent between seasonal time periods. During the spring/summer period (Figure 9; Appendix C), use and fallout at SSE, NSE, FOG-1 and FOG-4 decreased as additional turbines were brought online. However, during the fall period (Figure 10; Appendix C), use and fallout at SSE and NSE increased as additional units were brought online. Due to higher spring flows, a greater number of turbine patterns and turbine units were used in the spring than in the fall. Despite an outage of Turbine 1 during the fall period, use of SSE remained high.

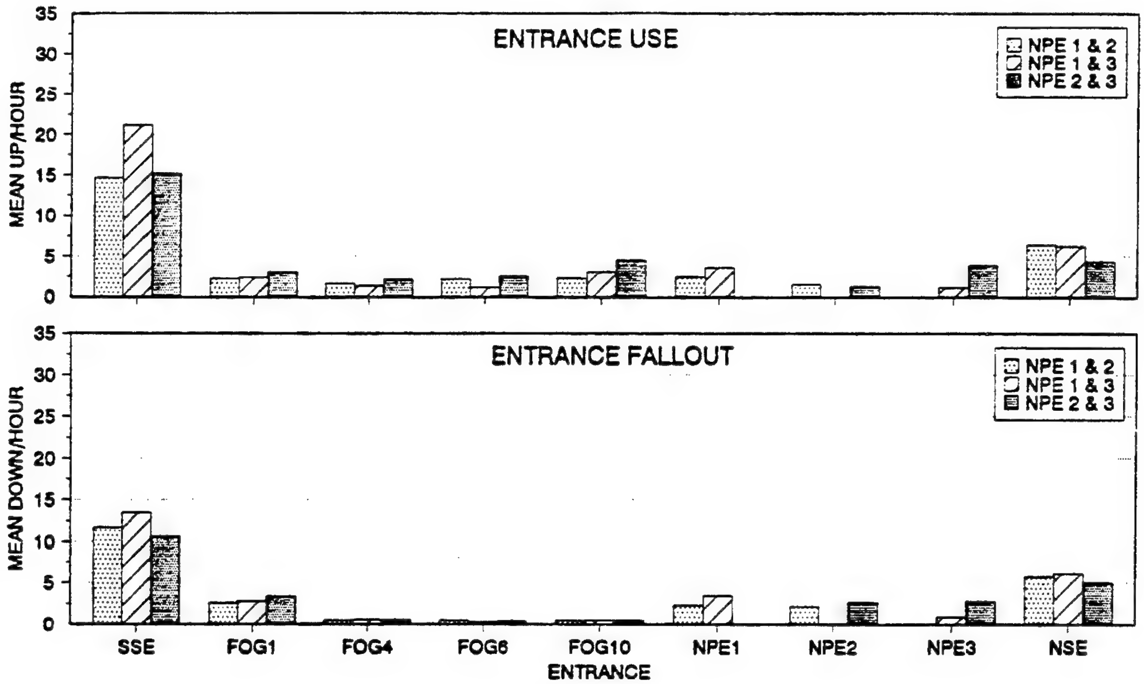

Figure 7. Mean hourly up counts and down counts at fishway entrances by combinations of two open north powerhouse entrances for the spring/summer period at Little Goose Dam, Snake River, 1991.

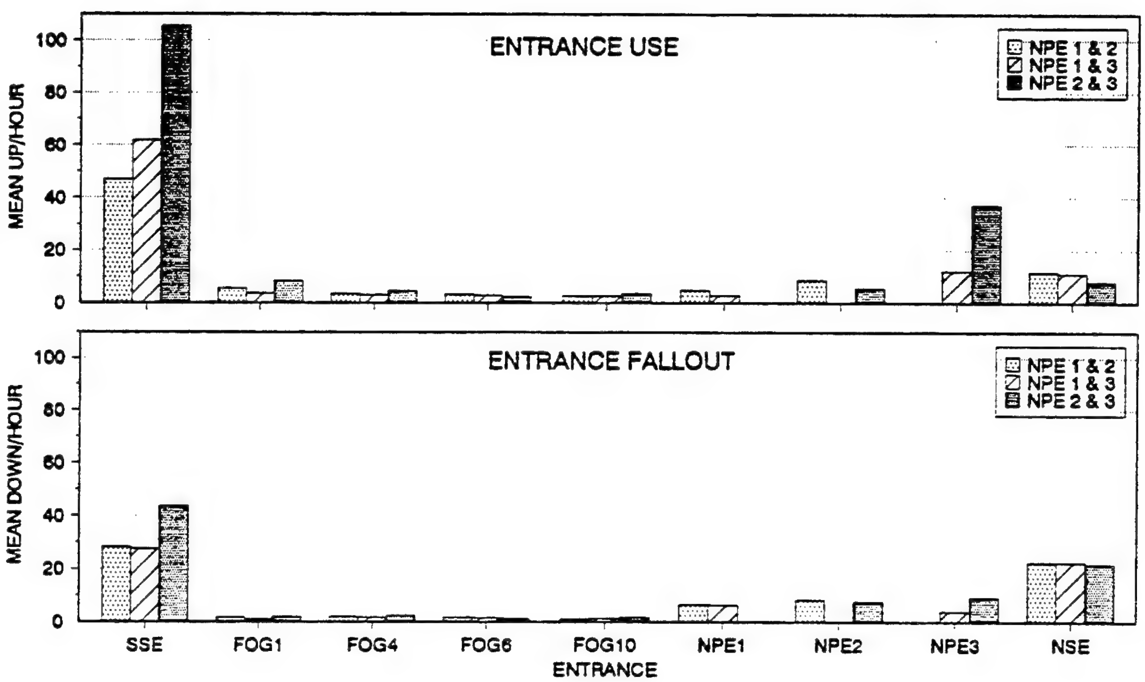

Figure 8. Mean hourly up counts and down counts at fishway entrances by combinations of two open north powerhouse entrances for the fall period at Little Goose Dam, Snake River, 1991.

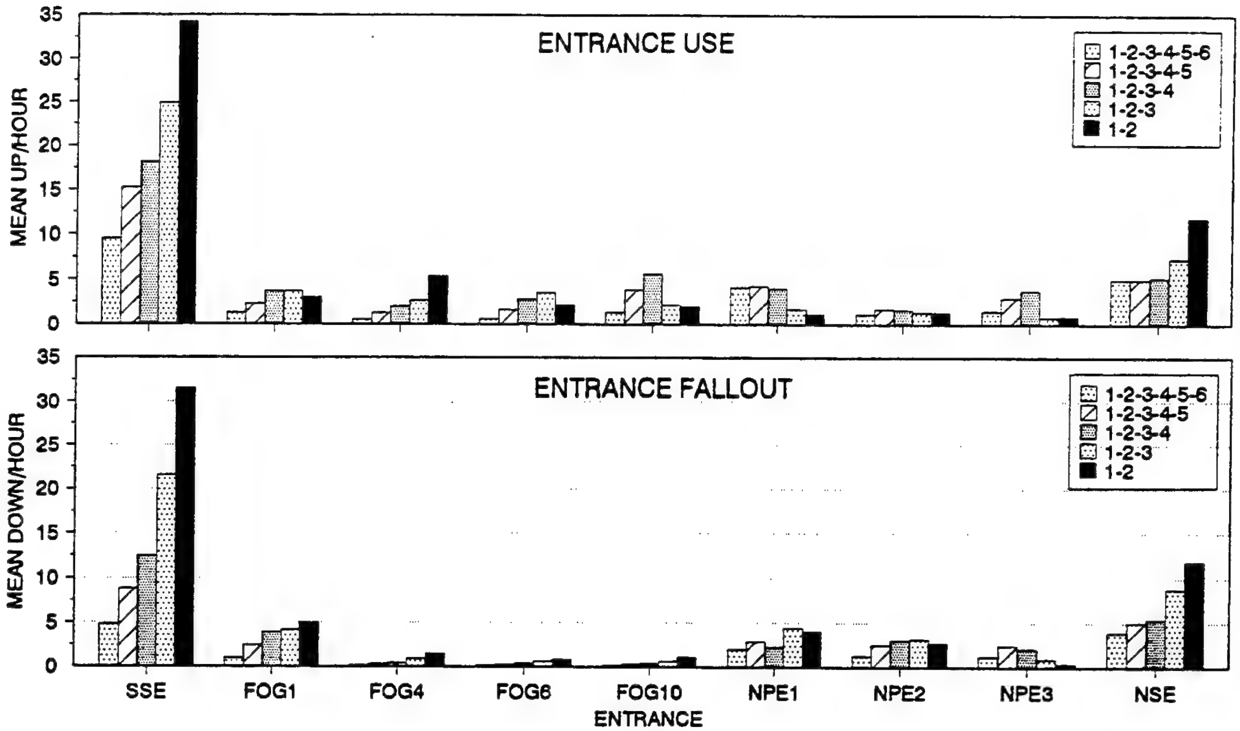

Figure 9. Mean hourly up counts and down counts at fishway entrances by patterns of turbine unit operation for the spring/summer period at Little Goose Dam, Snake River, 1991.

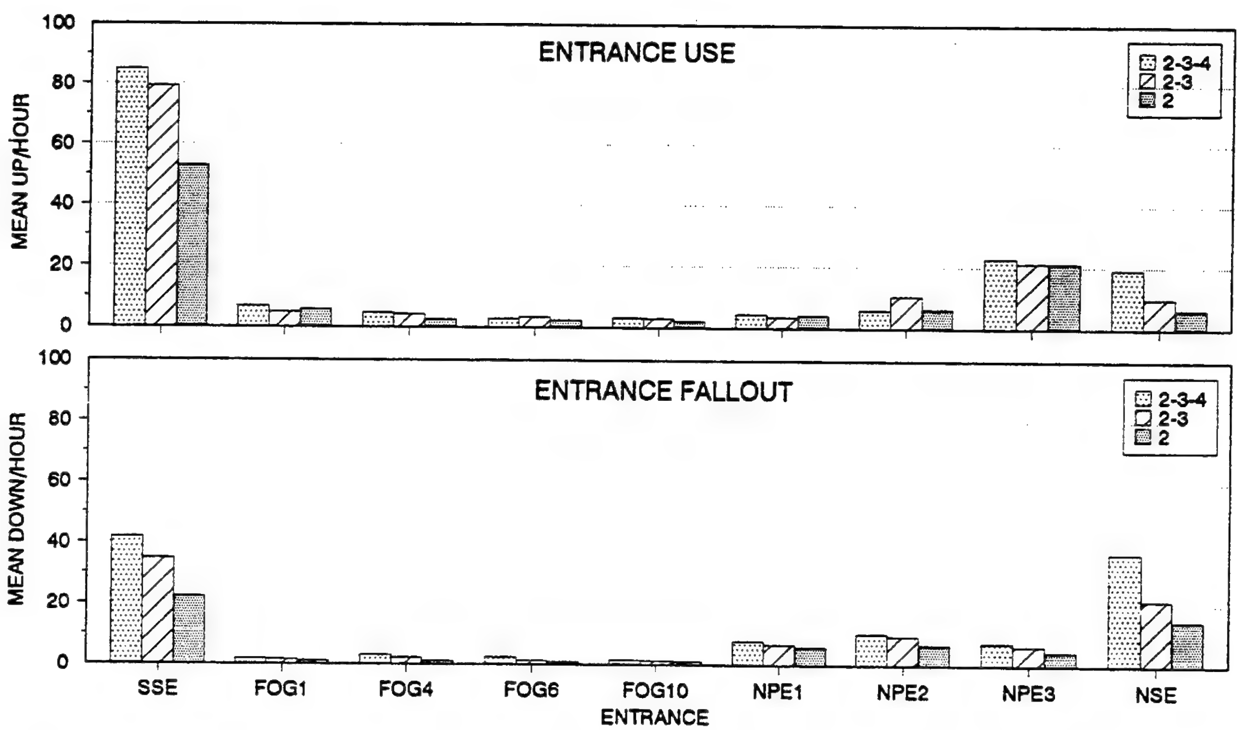

Figure 10. Mean hourly up counts and down counts at fishway entrances by patterns of turbine unit operation for the fall period at Little Goose Dam, Snake River, 1991.

There was some linear correlation between entrance use and fallout and total kcfs discharge for the spring/summer and fall periods (Table 2). Although correlations were small, most were statistically significant (*P* < 0.05) due to the large number of observations. *P* values are the associated probabilities that the true correlation coefficient is zero. In general, negative and positive correlations were higher for the southernmost entrances in the spring and fall, respectively. Positive and negative correlations reflected trends in entrance use and fallout with variations in turbine patterns (*see* Figures 9 and 10). As in the number of turbine operation patterns, total discharge was less in the fall than in the spring.

Table 2. Correlation (*r*) of hourly fishway entrance use and fallout with hourly powerhouse discharge (kcfs) during the spring/summer and fall study periods at Little Goose Dam, Snake River, 1991. *P* values are presented in parentheses.

Period, entrance	*N*[1]	Use *r* (*P*)	Fallout *r* (*P*)
Spring/summer			
SSE	1123	-0.32 (0.00)	-0.41 (0.00)
FOG-1	1123	-0.21 (0.00)	-0.31 (0.00)
FOG-4	1123	-0.33 (0.00)	-0.29 (0.00)
FOG-6	1123	-0.22 (0.00)	-0.23 (0.00)
FOG-10	1123	-0.08 (0.00)	-0.23 (0.06)
NPE-1	739	0.26 (0.00)	-0.17 (0.00)
NPE-2	760	-0.01 (0.77)	-0.16 (0.77)
NPE-3	601	-0.02 (0.64)	-0.04 (0.36)
NSE	1123	-0.17 (0.00)	-0.29 (0.00)
Fall			
SSE	595	0.14 (0.00)	0.31 (0.00)
FOG-1	596	0.09 (0.02)	0.16 (0.00)
FOG-4	596	0.16 (0.00)	0.27 (0.00)
FOG-6	596	0.09 (0.03)	0.28 (0.00)
FOG-10	596	0.08 (0.05)	0.11 (0.01)
NPE-1	407	0.02 (0.70)	0.05 (0.30)
NPE-2	395	-0.11 (0.02)	0.15 (0.00)
NPE-3	390	0.09 (0.06)	0.21 (0.00)
NSE	596	0.37 (0.00)	0.39 (0.00)

[1] *N* is the total number of hourly observations.

Lower Granite Dam

The proportion of tunnel counts that were estimated ranged from 19.6% (NPE-3) to 0.1% (FOG-1 and FOG-4)) during the spring/summer period and from 6.5% (FOG-10) to 0.3% (FOG-1, FOG-4, NSE) during the fall period. The majority of estimated hours per entrance was less than 5.0% of the total tunnel hours for both seasonal time periods.

The correlation between daily numbers of fish using fishway entrances and numbers of fish passing the fish viewing window was 0.33 and 0.60 ($P < 0.05$) for the periods 24 April - 17 July and 11 September - 13 November, respectively (Figure 11). Greater numbers of non-salmonids were observed at Lower Granite Dam than at Little Goose Dam, particularly during the spring/summer period. As at Little Goose Dam, non-salmonids were not counted at the fish viewing window.

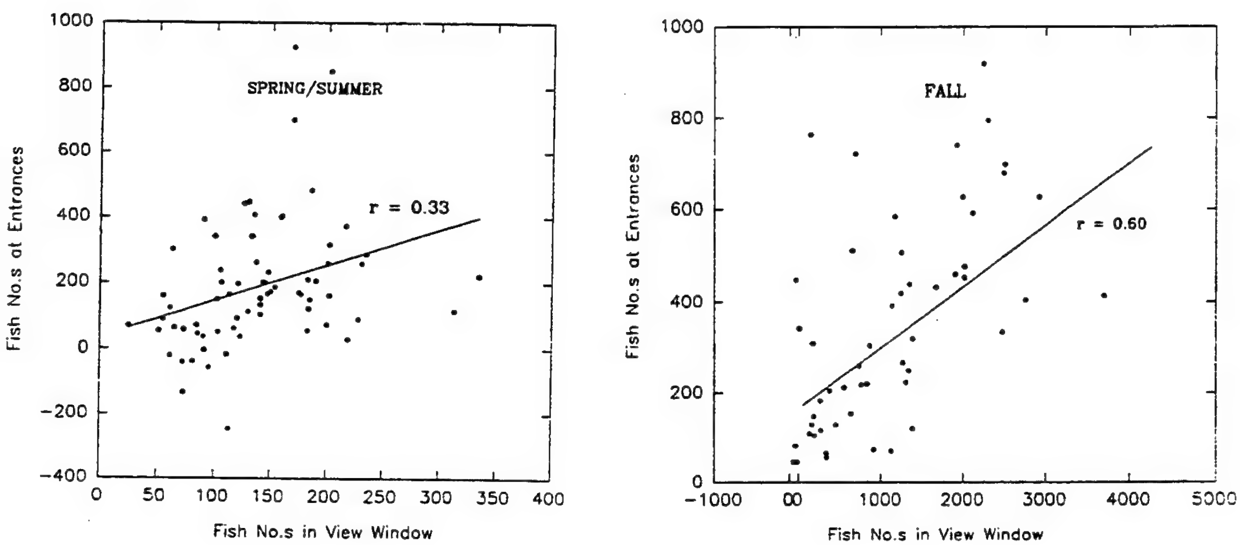

Figure 11. Correlation between daily numbers of fish using fishway entrances and numbers of fish passing the fish viewing window for the spring/summer and fall periods at Lower Granite Dam, Snake River, 1991.

"Fallout Fence" Effectiveness

Fallout, as calculated by Turner et al. (1983), varied similarly among entrances between 1981 and 1991 (Figure 12). Fallout was lowest at FOGs and greatest at NPE-1 and NPE-2. At NSE, down counts in 1991 were 81% of up counts, compared to only 50% in 1981. As at Little Goose Dam, a change in tunnel configuration at NSE between 1981 and 1991 may account for this difference.

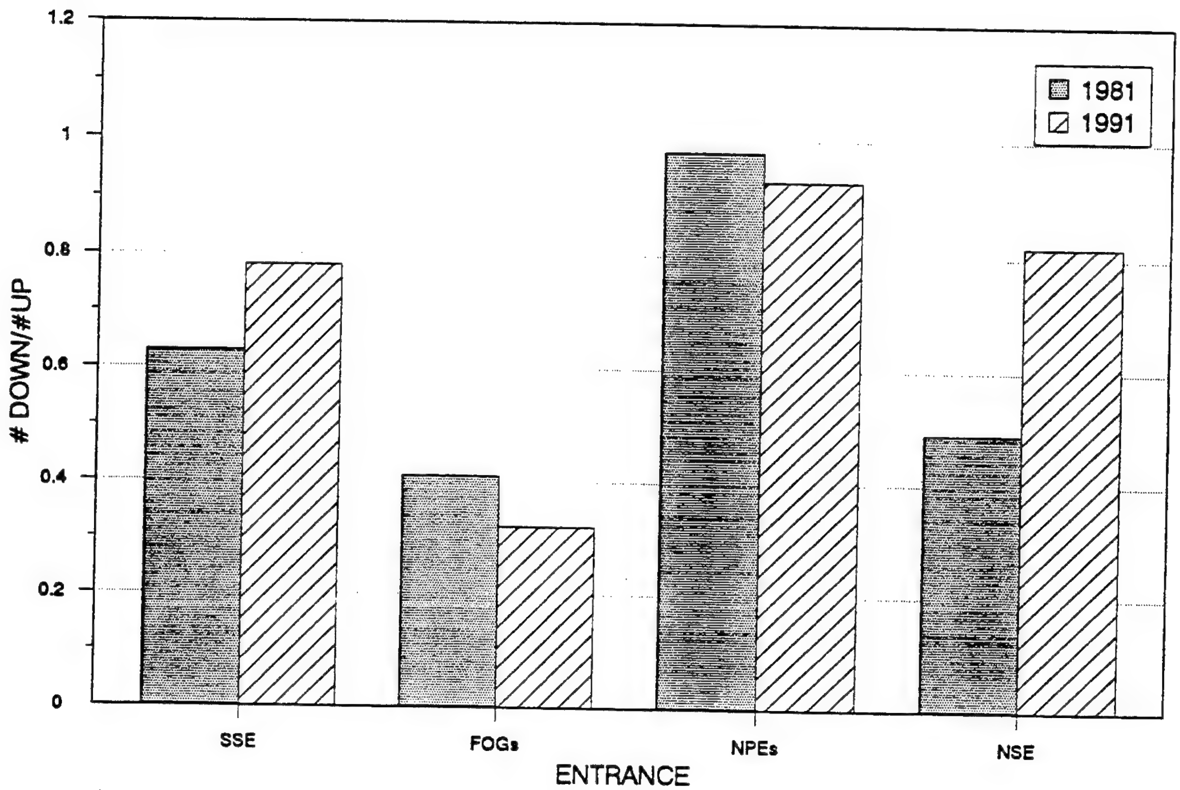

Figure 12. Fallout as calculated by Turner et al. (1983) for fishway entrances during spring 1981 and spring 1991 at Lower Granite Dam, Snake River.

Entrance Use and Fallout

As with Little Goose Dam, the same caveat on inability to distinguish species and greater useage of NSE and SSE by non-salmonids applies.

Patterns of entrance use and fallout were similar between seasonal time periods, and fallout was proportional to entrance use (Figure 13; Appendix A). Use and fallout were greatest at NSE and SSE during both periods. Use of NPE-3, which was relatively low during the spring/summer, was relatively high during the fall. In general, use of NPE-1, NPE-2, and the FOGs was low, but NPE-1 and NPE-2 had higher fallout rates than the FOGs.

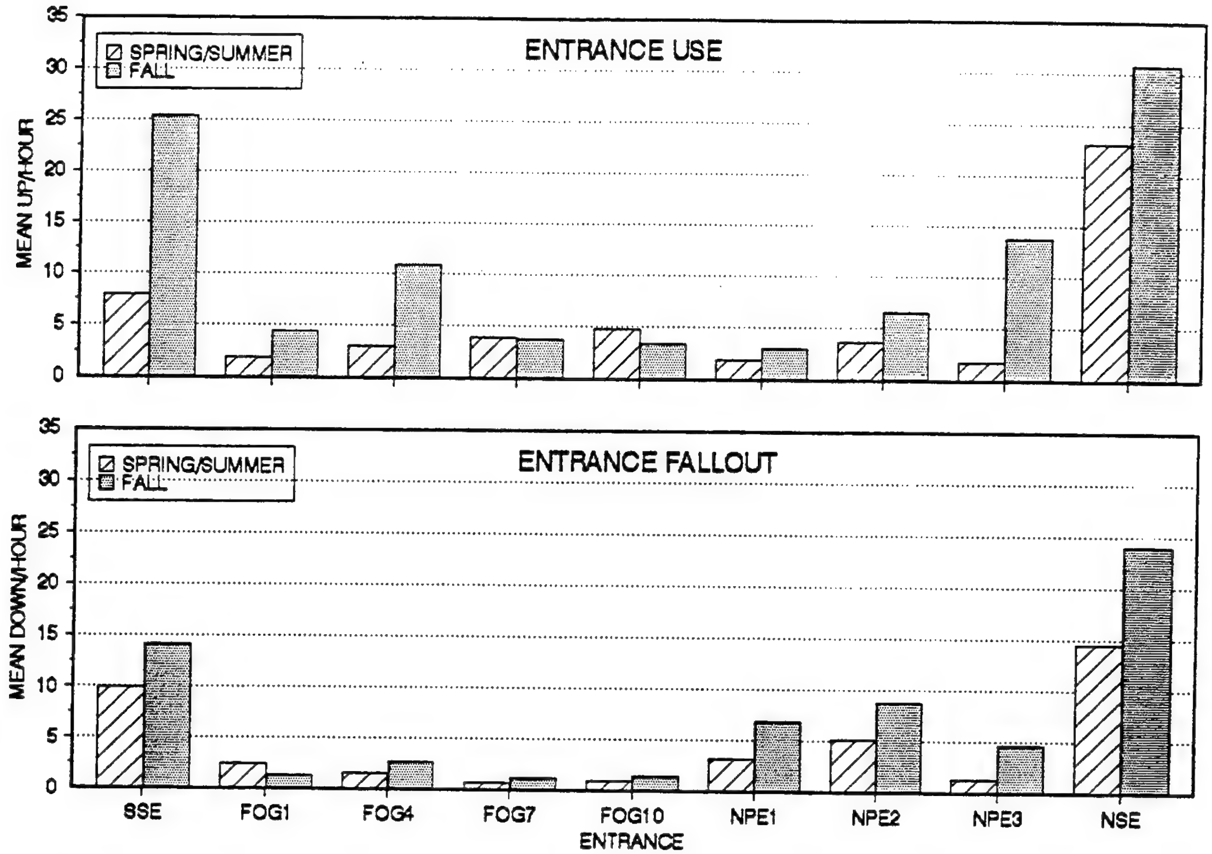

Figure 13. Mean hourly up counts and down counts at fishway entrances by seasonal time periods at Lower Granite Dam, Snake River, 1991.

Little variation in entrance use and fallout was apparent among the three combinations of NPEs that were open during the spring/summer period, although use of FOGs was slightly higher when NPE 1 and 2 were closed (Figure 14; Appendix B). During the fall period, closure of NPE 1 and 2 resulted in much higher use of SSE, FOG-1 and FOG-4 (Figure 15; Appendix B). When NPE 1 and 2 were open, use at NSE was relatively high and fallout was relatively low during both periods.

Entrance use and fallout varied with changes in turbine patterns during each seasonal time period (Figures 16 and 17; Appendix C). During the spring/summer period, use and fallout appeared to increase at SSE, FOG-4, and NSE as turbines were taken offline. In general, use at SSE, FOG-4, NPE-3, and NSE was relatively high when Units 1 and 2 were the only units operating. During the fall period, use and fallout at NSE and NPE-3 increased as turbines were brought online. In addition, the 1-2-3 turbine pattern resulted in relatively low use and high fallout at SSE.

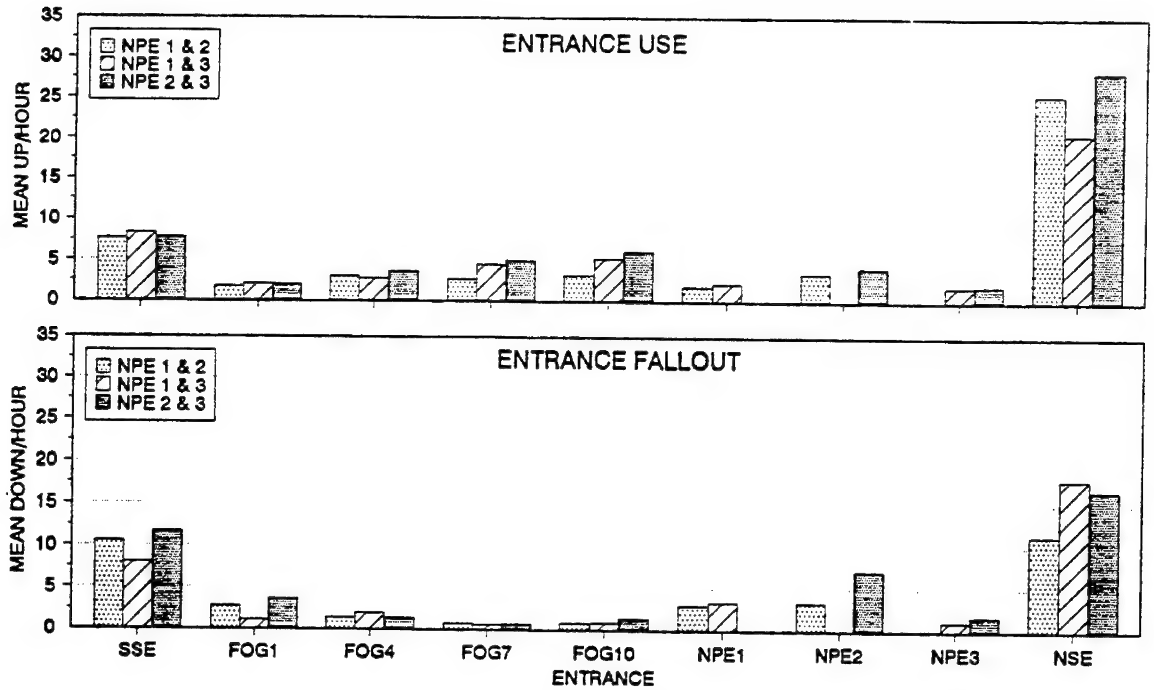

Figure 14. Mean hourly up counts and down counts at fishway entrances by combinations of two open north powerhouse entrances for the spring/summer period at Lower Granite Dam, Snake River, 1991.

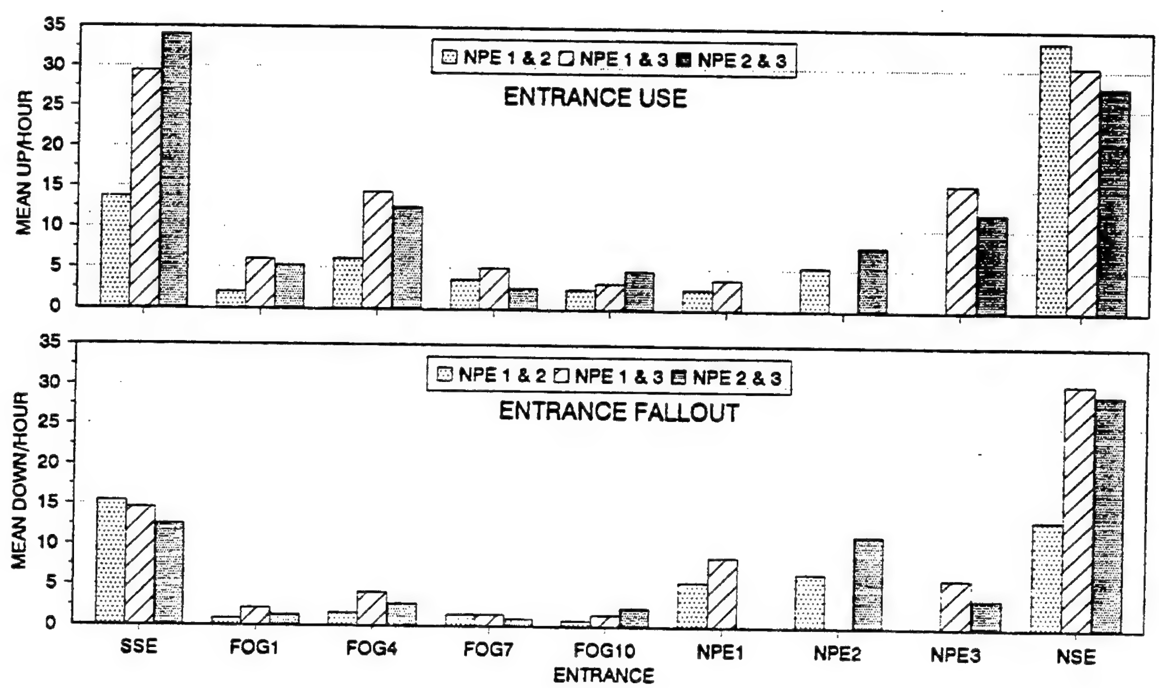

Figure 15. Mean hourly up counts and down counts at fishway entrances by combinations of two open north powerhouse entrances for the fall period at Lower Granite Dam, Snake River, 1991.

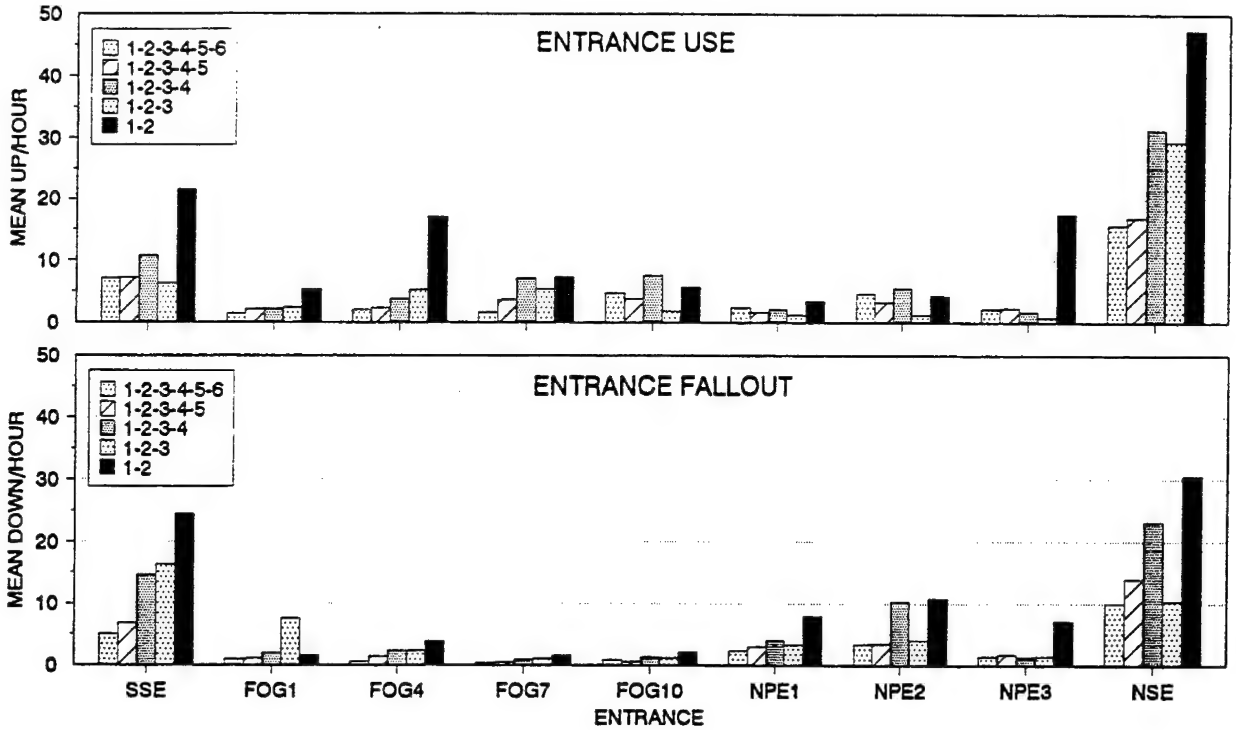

Figure 16. Mean hourly up counts and down counts at fishway entrances by patterns of turbine unit operation for the spring/summer period at Lower Granite Dam, Snake River, 1991.

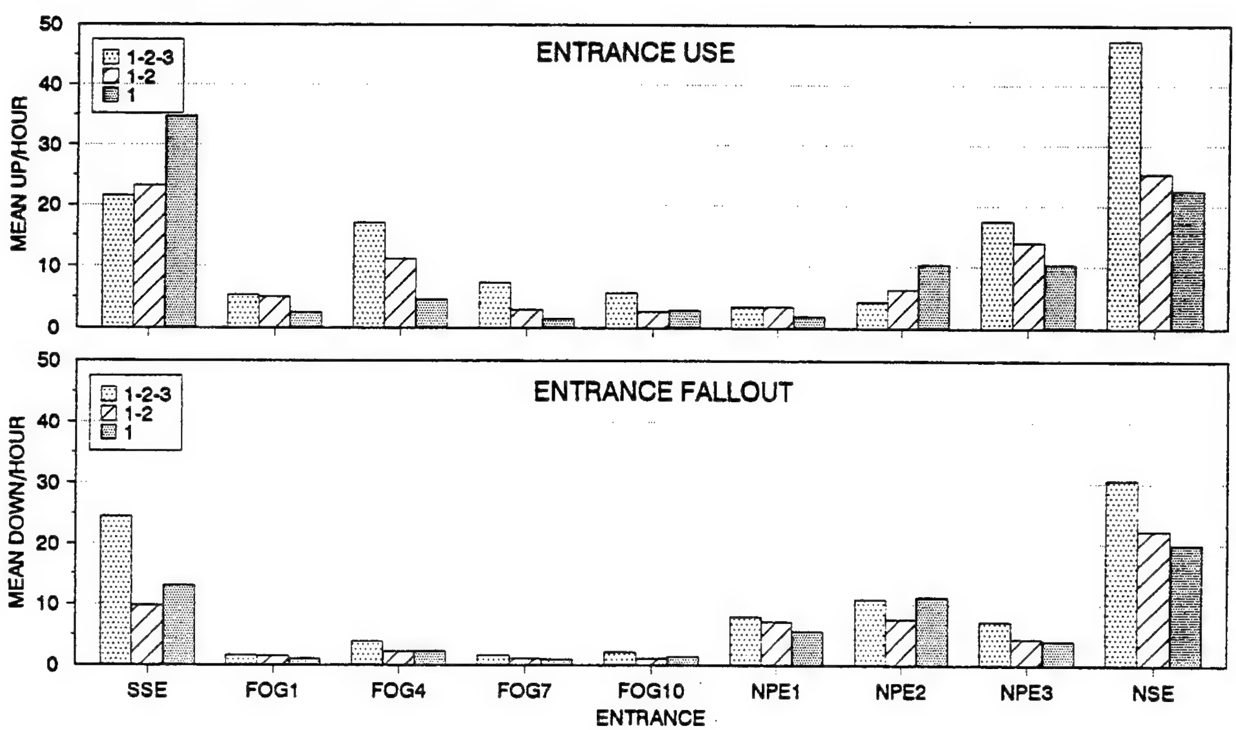

Figure 17. Mean hourly up counts and down counts at fishway entrances by patterns of turbine unit operation for the fall period at Lower Granite Dam, Snake River, 1991.

There was some linear correlation between entrance use and fallout and total kcfs discharge for the spring/summer and fall periods (Table 4). Although correlations were small, most were statistically significant ($P < 0.05$) due to the large number of observations. Negative correlations were most evident for the southernmost entrances in the spring, particulary with fallout. Higher positive correlations in regard to entrance use were shown for the powerhouse (FOGs) and northernmost entrances in the fall.

Table 4. Correlation (r) of hourly fishway entrance use and fallout with hourly powerhouse discharge (kcfs) during the spring/summer and fall study periods at Lower Granite Dam, Snake River, 1991. P values are presented in parentheses.

Period, entrance	N[1]	Use r (P)	Fallout r (P)
Spring/summer			
SSE	1045	-0.04 (0.15)	-0.31 (0.00)
FOG-1	1112	-0.11 (0.00)	-0.36 (0.00)
FOG-4	1112	-0.21 (0.00)	-0.26 (0.00)
FOG-7	1112	-0.15 (0.00)	-0.19 (0.00)
FOG-10	1112	-0.06 (0.06)	-0.09 (0.00)
NPE-1	758	0.12 (0.00)	- 0.14 (0.00)
NPE-2	726	0.19 (0.00)	-0.11 (0.00)
NPE-3	450	0.11 (0.02)	0.02 (0.73)
NSE	1111	-0.19 (0.00)	-0.10 (0.00)
Fall			
SSE	607	-0.10 (0.02)	0.34 (0.00)
FOG-1	607	0.10 (0.01)	0.07 (0.08)
FOG-4	607	0.31 (0.00)	0.25 (0.00)
FOG-7	607	0.48 (0.00)	0.15 (0.00)
FOG-10	597	0.23 (0.00)	0.14 (0.00)
NPE-1	412	0.05 (0.28)	0.17 (0.00)
NPE-2	406	-0.16 (0.00)	0.12 (0.02)
NPE-3	396	0.24 (0.00)	0.17 (0.00)
NSE	607	0.37 (0.00)	0.13 (0.00)

[1] N is the total number of hourly observations.

DISCUSSION

Because correlations between daily numbers of fish using fishway entrances and numbers of fish passing the adult fish viewing window were low during some periods, we question the validity of some tunnel count data. There may be three reasons for low correlations. Under certain conditions, turbulent water, debris, and other factors may have triggered false counts. In addition, members of a large population of carp in the fishway may have been frequently counted. Visual observations throughout the season indicated that much larger numbers of carp were in the fishway at Lower Granite Dam than at Little Goose Dam and during the spring/summer period than during the fall. Finally, by placing tunnels in the collection channel to monitor passage from SSE and NSE, fish may have triggered upstream and downstream counts while remaining in the fishway; many of these fish were most likely non-salmonids. Although inaccuracies in tunnel counts existed, patterns of fishway entrance use and fallout remained fairly constant over time, indicating the relative magnitude of tunnel counts during seasonal time periods may have been fairly representative of fishway activity.

In an effort to identify and decrease biases associated with electronic tunnel equipment, we have tested and proposed using low-light, underwater video cameras as a method of validating electronic tunnel counts. During 1992, we plan to mount video cameras on selected tunnels at Lower Granite Dam, quantitatively compare video counts to tunnel counts, and qualitatively assess sources of bias. Additionally, we will assess the feasibility of using underwater video cameras as an independent method of monitoring fish passage by installing video cameras directly in SSE-1, SSE-2, NSE-1, and NSE-2.

Little Goose Dam

The "fallout fence" placed in the fishway near NPE-1 and NPE-2 did not appear to be effective in reducing fallout through those entrances during the 1991 low flow year. The value of the fence in reducing fishway fallout in a high flow, spill scenario has yet to be evaluated. Although the fallout fence may have kept fish that entered NPE-3 and NSE from falling out at NPE-1 and NPE-2, the fence may have corralled fish moving downstream in the collection channel from the south end and guided them out NPE-1 and NPE-2. The close proximity of the fallout fence to NPE-1 and NPE-2 may have inhibited use of these entrances or may have caused fish that entered these entrances to turn and immediately fall out. Because of the location of the fence, fish that entered NPE-1 may have been forced to pass through the high velocity outflow area above NPE-2 causing them to follow the outflow and fall out at NPE-2.

Alternatives to the fallout fence, such as fyking, may be necessary to reduce fallout through NPE-1 and NPE-2. However, because we could not design and install alternatives before our 1992 field season, we will continue to assess fallout fence effectiveness for a second year at Lower Granite Dam using a combination of eletronic tunnels and underwater video cameras. It should be noted that the presence of the fallout fence may have confounded our evaluation of combinations of two north powerhouse entrances that were open because of its effects on use and fallout at NPE-1 and NPE-2. If changes are to be made to the fallout fence we should re-evaluate use and fallout at north powerhouse entrances when various combinations are open.

Fallout was proportional to entrance use for all entrances during each seasonal time period. This trend was similar to that reported by Johnson et al. (1979) for research conducted at Bonneville Dam. In general, where more fish entered, more fish fell out. We believe that the relatively high magnitude of fallout at some entrances should be of concern, and plans to reduce fallout at these entrances should be incorporated into future study designs.

Since there was little difference in use and fallout among combinations of two north powerhouse entrances that were open, we examined differences among individual entrances within each pair. We believe that the relatively high use and low fallout at NPE-3, and the little difference in use and fallout between NPE-1 and NPE-2, indicates that a combination of NPE-3 and either NPE-1 and NPE-2 would be a suitable combination for either period.

Our assessments of fishway entrance use and fallout were comparable to results reported by Turner et al. (1983). Regardless of the time of year or powerhouse operating conditions, use was high at SSE. We believe that the direct effects of total kcfs discharge through the powerhouse may not be as important a factor affecting entrance use and fallout as discharge through individual turbines. Individual turbine discharge had some influence on SSE use; operation of only the southernmost turbines tended to increase passage during the spring/summer periods. However, since SSE was also used most during the fall when turbine Unit 1 was not operating, it is likely that use of the entrance is more closely related to its proximity to the shoreline, rather than attraction flow from Unit 1. This would also explain the relatively high use of NSE; high use at NSE may also be a result of it being the most north shore oriented entrance. These findings are consistent with results reported from tunnel studies conducted at other facilities (Johnson et al. 1979; Turner et al. 1984).

The difference in fallout, as calculated by Turner et al. (1983), at the NSE between 1981 and 1991 is probably a function of the differences in tunnel design between the two years. In 1981, two tunnels were mounted on a picketed frame near the surface in the middle of the collection channel. Fish were consequently forced upward and toward the middle of the channel from areas near the bottom and sides of the collection channel. Once through the tunnels, fish probably redistributed themselves near the bottom and sides of the channel and may not have encountered the tunnels again (Turner et al. 1983). In 1991, we used an array of 16 tunnels. This array allowed fish to use the entire water column and still pass through the tunnels.

As discussed previously, fyking NPE-1 and NPE-2 or modifying the fallout fence may reduce the problem of fallout through NPE-1 and NPE-2. We agree with recommendations made by Turner et al. (1983) that at least one of the north powerhouse entrances should be closed to reduce fallout if suitable modifications to the entrances cannot be made. This would also help to meet fishway operating criteria needs and alleviate water supply problems during periods of low tailwater. However, further research should be conducted to determine what affects operation of only one north powerhouse entrance would have on fishway entrance use and fallout. If fallout is attributable to fish moving down the collection channel and being guided out by the fence, then removal of the fence or increased transport velocities along the collection channel may facilitate upstream movement.

The current location of open floating orifice gates is probably suitable given their relatively low fallout. Fallout at FOG-1 may be a result of its proximity to the SSE and the base of the fish ladder, an area where large numbers of fish may congregate at certain times. FOG-1 could be fyked to reduce fallout, or FOG-1 closed and FOG-2 opened. If additional water is needed toward the north end of the fishway in the future, FOG-1, or all FOGs, could be closed.

Lower Granite Dam

The fallout fence placed near NPE-1 and NPE-2 did not appear to be effective in reducing fallout through those entrances in 1991. We believe factors that influenced fallout at Little Goose Dam may have affected fallout at Lower Granite Dam. Because of our concern about the validity of our data, we believe it is necessary to re-evaluate the effectiveness of the fallout fence during 1992 using underwater video cameras.

Our assessment of fishway entrance use and fallout was not consistent with results reported by Turner et al. (1983). The high use of NSE during each seasonal time period was most likely related to the placement of tunnels in the collection channel and the presence of carp in that section of the fishway. The proportionally higher use of SSE during the fall, when the correlation with window counts was higher, is probably more representative of actual entrance activity. To more accurately gauge entrance and fallout activity in 1992, we will determine the feasibility of placing underwater video cameras directly in NSE and SSE.

As mentioned above, and consistent with observations made at Little Goose Dam, NPE-1 and NPE-2 received little use, and fallout was usually higher than use. To meet established fishway operating criteria, operation of only one north powerhouse entrance during periods of low tailwater may be feasible. However, further tests should be conducted to determine what effect operation of only one north powerhouse entrance would have on fishway entrance use and fallout. We will concentrate research in 1992 on evaluating use and fallout at NPE-1 and NPE-2 before making further recommendations concerning their use.

The current location and number of open floating orifice gates is probably suitable given their relatively low fallout. As at Little Goose Dam, higher fallout rates at FOG-1 may be a result of its proximity to SSE and the base of the fish ladder, an area where large numbers of fish may congregate at certain times. FOG-1 could be fyked to reduce fallout, or if additional water is needed in the future, FOG-1 could be the closed.

Similar to results obtained at Little Goose Dam, there was little difference in use and fallout among combinations of two north powerhouse entrances that were open. We believe that the relatively high use and low fallout at NPE-3, and the little difference in use and fallout between NPE-1 and NPE-2, indicates that a combination of NPE-3 and either NPE-1 and NPE-2 would be a suitable combination for either period.

RECOMMENDATIONS

1. Design and evaluate during each seasonal period a video monitoring system for use as a method of validating electronic tunnel counts, and assess its feasibility as a potential replacement for electronic tunnels.

2. Design and test during each seasonal period a video system that could be deployed directly in the north shore and south shore entrances at Lower Granite Dam to more adequately monitor fish passage.

3. Close either NPE-1 or NPE-2 at Little Goose and Lower Granite dams, and open NPE-3 at both dams during periods of zero spill. Evaluate the closure of these entrances.

4. Close or modify FOG-1 at Little Goose Dam to reduce fallout, particularly in the spring/summer period; open FOG-2 if FOG-1 is closed.

5. Design a turbine operation schedule for Lower Granite Dam in 1992 that would facilitate evaluation of effects of powerhouse operation on entrance use and efficiency.

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APPENDIX A

Minimum, Maximum, Mean, and Standard Deviation Values for Total Hourly Upstream and Dowstream Counts at Fishway Entrances at Lower Granite and Little Goose Dams

Appendix Table A-1. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances during the spring/summer and fall periods at Little Goose Dam, Snake River, 1991.

Period, entrance	N	Upstream Counts Min	Upstream Counts Max	Upstream Counts Mean	Upstream Counts SD	Downstream Counts Min	Downstream Counts Max	Downstream Counts Mean	Downstream Counts SD
Spring/ summer									
SSE	1125	0	112	16.92	14.63	0	114	11.89	14.23
FOG-1	1125	0	25	2.54	3.35	0	30	2.86	3.74
FOG-4	1125	0	20	1.74	2.64	0	6	0.46	0.93
FOG-6	1125	0	25	1.94	3.25	0	6	0.33	0.73
FOG-10	1125	0	48	3.29	5.51	0	6	0.41	0.80
NPE-1	739	0	37	2.96	4.56	0	21	2.83	3.24
NPE-2	762	0	26	1.39	2.20	0	24	2.37	2.78
NPE-3	603	0	42	2.52	4.91	0	48	1.82	4.03
NSE	1125	0	45	5.61	5.20	0	38	5.63	5.22
Fall									
SSE	598	0	396	70.34	58.35	0	124	32.67	23.15
FOG-1	599	0	48	5.69	7.37	0	18	1.39	2.08
FOG-4	599	0	30	3.60	4.18	0	11	1.87	2.17
FOG-6	599	0	22	2.77	3.87	0	12	1.32	1.68
FOG-10	599	0	21	2.79	3.90	0	10	1.25	1.64
NPE-1	410	0	26	3.76	5.06	0	31	6.38	5.30
NPE-2	395	0	53	7.08	8.10	0	32	7.96	6.64
NPE-3	393	0	149	24.11	27.05	0	71	6.37	7.47
NSE	599	0	69	10.23	10.23	0	116	22.10	17.13

Appendix Table A-2. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances during the spring/summer and fall periods at Lower Granite Dam, Snake River, 1991.

		Upstream Counts				Downstream Counts			
Period, entrance	N	Min	Max	Mean	SD	Min	Max	Mean	SD
Spring/ summer									
SSE	1046	0	67	7.91	7.93	0	105	9.96	12.90
FOG-1	1113	0	24	1.93	2.80	0	45	2.45	5.02
FOG-4	1113	0	56	3.11	5.35	0	30	1.58	2.94
FOG-7	1113	0	59	3.99	6.86	0	20	0.65	1.47
FOG-10	1113	0	76	4.79	8.35	0	16	0.97	1.62
NPE-1	759	0	27	1.97	3.04	0	27	3.14	3.39
NPE-2	726	0	45	3.73	5.35	0	38	5.19	5.74
NPE-3	451	0	18	1.84	3.22	0	17	1.38	2.48
NSE	1112	0	201	23.18	27.07	0	123	14.59	16.52
Fall									
SSE	610	0	363	25.43	28.02	0	135	14.20	15.62
FOG-1	610	0	50	4.38	6.59	0	13	1.37	2.01
FOG-4	610	0	126	10.91	13.96	0	20	2.72	3.66
FOG-7	610	0	25	3.75	4.80	0	10	1.21	1.55
FOG-10	600	0	43	3.43	6.05	0	33	1.40	3.40
NPE-1	415	0	153	3.10	8.92	0	50	6.97	6.85
NPE-2	406	0	64	6.51	7.49	0	62	8.86	8.60
NPE-3	399	0	74	13.82	14.11	0	47	4.75	8.43
NSE	610	0	177	30.73	29.05	0	218	24.05	26.70

APPENDIX B

Minimum, Maximum, Mean, and Standard Deviation Values for Total Hourly Upstream and Downstream Counts at Fishway Entrances by Combinations of Two Open North Powerhouse Entrances at Lower Granite and Little Goose Dams

Appendix Table B-1. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances by combinations of two open north powerhouse entrances during the spring/summer period at Little Goose Dam, Snake River, 1991.

		Upstream Counts				Downstream Counts			
Comb., entrance	N	Min	Max	Mean	SD	Min	Max	Mean	SD
NPE-1 & 2									
SSE	376	0	71	14.65	13.69	0	97	11.65	14.71
FOG-1	376	0	21	2.20	3.06	0	16	2.51	3.29
FOG-4	376	0	20	1.66	2.96	0	6	0.40	0.89
FOG-6	376	0	25	2.14	3.87	0	6	0.44	0.91
FOG-10	376	0	28	2.32	3.84	0	5	0.41	0.80
NPE-1	376	0	34	2.44	3.71	0	14	2.25	2.37
NPE-2	376	0	26	1.46	2.25	0	23	2.10	2.65
NSE	376	0	45	6.37	6.08	0	38	5.77	5.52
NPE-1 & 3									
SSE	363	0	112	21.16	16.77	0	114	13.48	15.05
FOG-1	363	0	19	2.35	3.10	0	17	2.73	3.39
FOG-4	363	0	10	1.37	1.80	0	5	0.48	0.97
FOG-6	363	0	12	1.10	1.62	0	5	0.20	0.54
FOG-10	363	0	48	3.04	5.44	0	6	0.43	0.83
NPE-1	363	0	37	3.51	5.25	0	21	3.44	3.86
NPE-3	293	0	24	1.11	2.38	0	16	0.82	1.82
NSE	363	0	27	6.18	5.29	0	32	6.11	5.57
NPE-2 & 3									
SSE	386	0	68	15.15	12.35	0	78	10.61	12.77
FOG-1	386	0	25	3.06	3.78	0	30	3.33	4.37
FOG-4	386	0	18	2.16	2.90	0	6	0.51	0.92
FOG-6	386	0	20	2.53	3.56	0	4	0.35	0.66
FOG-10	386	0	43	4.46	6.63	0	5	0.39	0.77
NPE-2	386	0	24	1.31	2.15	0	24	2.63	2.88
NPE-3	310	0	42	3.85	6.16	0	48	2.76	5.16
NSE	386	0	22	4.35	3.76	0	25	5.05	4.50

Appendix Table B-2. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances by combinations of two open north powerhouse entrances during the fall period at Little Goose Dam, Snake River, 1991.

Comb., entrance	N	Upstream Counts				Downstream Counts			
		Min	Max	Mean	SD	Min	Max	Mean	SD
NPE-1 & 2									
SSE	206	0	175	46.89	32.29	0	100	28.06	16.90
FOG-1	206	0	37	5.37	6.31	0	18	1.48	2.47
FOG-4	206	0	18	3.42	3.65	0	11	1.76	2.04
FOG-6	206	0	22	3.21	4.04	0	12	1.54	1.94
FOG-10	206	0	17	2.55	3.33	0	8	1.00	1.32
NPE-1	206	0	26	4.81	5.73	0	31	6.53	5.60
NPE-2	206	0	53	8.61	9.67	0	29	8.27	7.07
NSE	206	0	53	11.56	10.00	0	85	22.41	15.56
NPE-1 & 3									
SSE	204	0	223	61.74	45.93	0	81	27.45	18.77
FOG-1	204	0	20	3.65	4.37	0	8	0.95	1.47
FOG-4	204	0	19	3.02	3.44	0	9	1.66	2.07
FOG-6	204	0	19	2.75	3.80	0	8	1.35	1.63
FOG-10	204	0	21	2.59	3.63	0	8	1.16	1.47
NPE-1	204	0	22	2.70	4.02	0	30	6.23	5.00
NPE-3	204	0	59	12.18	9.69	0	22	3.86	4.23
NSE	204	0	56	11.05	10.85	0	116	22.30	17.69
NPE-2 & 3									
SSE	188	0	396	105.37	74.27	0	124	43.39	29.10
FOG-1	189	0	48	8.24	9.86	0	9	1.76	2.09
FOG-4	189	0	30	4.42	5.21	0	11	2.24	2.37
FOG-6	189	0	17	2.32	3.73	0	8	1.06	1.37
FOG-10	189	0	19	3.28	4.67	0	10	1.63	2.02
NPE-2	189	0	24	5.42	5.49	0	32	7.62	6.13
NPE-3	189	0	149	36.99	33.21	0	71	9.07	9.10
NSE	189	0	69	7.90	9.43	0	83	21.54	18.19

Appendix Table B-3. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances by combinations of two open north powerhouse entrances during the spring/summer period at Lower Granite Dam, Snake River, 1991.

		Upstream Counts				Downstream Counts			
Comb., entrance	N	Min	Max	Mean	SD	Min	Max	Mean	SD
NPE-1 & 2									
SSE	307	0	43	7.61	7.25	0	70	10.48	14.11
FOG-1	373	0	16	1.72	2.65	0	45	2.77	5.98
FOG-4	373	0	42	3.05	5.11	0	16	1.34	2.31
FOG-7	373	0	34	2.63	4.75	0	20	0.73	2.04
FOG-10	373	0	28	3.17	4.21	0	6	0.76	1.10
NPE-1	373	0	21	1.76	2.86	0	19	2.95	3.26
NPE-2	373	0	45	3.39	5.07	0	18	3.33	3.03
NSE	373	0	201	21.05	25.40	0	77	11.33	11.48
NPE-1 & 3									
SSE	386	0	67	8.30	8.01	0	56	8.02	9.34
FOG-1	386	0	24	2.08	3.00	0	11	1.07	1.95
FOG-4	386	0	30	2.73	5.06	0	30	1.96	3.89
FOG-7	386	0	40	4.47	6.48	0	8	0.56	1.04
FOG-10	386	0	75	5.19	8.20	0	11	0.82	1.33
NPE-1	386	0	27	2.17	3.19	0	27	3.33	3.50
NPE-3	258	0	18	1.79	3.20	0	9	1.11	1.88
NSE	386	0	141	20.55	22.22	0	116	15.82	17.91
NPE-2 & 3									
SSE	353	0	61	7.75	8.40	0	105	11.64	14.77
FOG-1	354	0	19	2.01	2.71	0	41	3.62	5.83
FOG-4	354	0	56	3.58	5.87	0	18	1.40	2.18
FOG-7	354	0	59	4.91	8.70	0	8	0.67	1.10
FOG-10	354	0	76	6.06	11.09	0	16	1.36	2.20
NPE-2	354	0	34	4.09	5.62	0	38	7.16	7.12
NPE-3	193	0	15	1.90	3.25	0	17	1.74	3.08
NSE	353	0	184	28.29	32.45	0	123	16.69	18.81

Appendix Table B-4. Minimum, maximum, mean, nd standard deviation values for total hourly upstream and downstream counts at fishway entrances by combinations of two open north powerhouse entrances during the fall period at Lower Granite Dam, Snake River, 1991.

Comb., entrance	N	Upstream Counts Min	Max	Mean	SD	Downstream Counts Min	Max	Mean	SD
NPE-1 & 2									
SSE	211	0	46	13.69	9.40	0	94	15.40	18.69
FOG-1	211	0	14	1.98	2.70	0	6	0.75	1.12
FOG-4	211	0	45	6.08	6.88	0	17	1.50	2.49
FOG-7	211	0	18	3.64	3.85	0	8	1.37	1.60
FOG-10	211	0	28	2.48	4.37	0	14	0.67	1.64
NPE-1	211	0	20	2.54	3.92	0	25	5.45	4.20
NPE-2	211	0	64	5.27	6.96	0	23	6.58	4.66
NSE	211	0	177	33.56	33.47	0	47	13.33	9.48
NPE-1 & 3									
SSE	204	0	115	29.37	25.83	0	67	14.57	13.82
FOG-1	204	0	50	5.99	8.72	0	13	2.07	2.66
FOG-4	204	0	126	14.37	17.29	0	20	4.05	4.44
FOG-7	204	0	25	4.97	6.01	0	10	1.37	1.67
FOG-10	204	0	40	3.14	5.78	0	17	1.36	2.35
NPE-1	204	0	153	3.68	12.07	0	50	8.53	8.52
NPE-3	204	0	74	15.56	14.68	0	47	5.95	9.08
NSE	204	0	127	30.43	27.27	0	218	30.36	33.88
NPE-2 & 3									
SSE	195	0	363	34.04	37.81	0	135	12.52	13.55
FOG-1	195	0	28	5.28	6.24	0	9	1.32	1.73
FOG-4	195	0	52	12.53	14.39	0	19	2.67	3.34
FOG-7	195	0	16	2.57	3.93	0	7	0.85	1.30
FOG-10	195	0	43	4.74	7.50	0	33	2.23	5.11
NPE-2	195	0	38	7.85	7.83	0	62	11.33	10.91
NPE-3	195	0	58	12.01	13.29	0	41	3.51	7.52
NSE	195	0	132	27.97	25.34	0	170	29.04	27.35

APPENDIX C

Minimum, Maximum, Mean, and Standard Deviation Values for Total Hourly Upstream and Downstream Counts at Fishway Entrances by Turbine Operation Pattern at Lower Granite and Little Goose Dams

Appendix Table C-1. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances by turbine operation pattern during the spring/summer period at Little Goose Dam, Snake River, 1991.

Units operating, entrance	N	Upstream Counts Min	Max	Mean	SD	Downstream Counts Min	Max	Mean	SD
Units 1-6									
SSE	204	0	45	9.54	9.68	0	59	4.75	5.73
FOG-1	204	0	16	1.25	2.38	0	10	0.96	1.54
FOG-4	204	0	6	0.52	0.93	0	5	0.16	0.52
FOG-6	204	0	7	0.61	1.16	0	3	0.15	0.41
FOG-10	204	0	17	1.31	2.37	0	3	0.19	0.51
NPE-1	121	0	37	4.10	6.42	0	11	2.02	2.45
NPE-2	156	0	14	1.09	1.78	0	14	1.28	1.73
NPE-3	211	0	10	1.49	2.23	0	7	1.17	1.75
NSE	204	0	23	4.97	4.64	0	17	3.87	3.82
Units 1-5									
SSE	286	0	71	15.22	12.30	0	97	8.77	11.63
FOG-1	286	0	21	2.25	3.38	0	30	2.42	3.81
FOG-4	286	0	18	1.25	2.34	0	4	0.27	0.62
FOG-6	286	0	18	1.59	2.65	0	3	0.20	0.48
FOG-10	286	0	36	3.82	6.40	0	4	0.31	0.71
NPE-1	170	0	25	4.25	4.90	0	18	2.88	3.19
NPE-2	209	0	24	1.67	2.62	0	24	2.53	3.33
NPE-3	187	0	42	2.95	5.84	0	48	2.41	5.85
NSE	286	0	45	4.98	5.27	0	38	4.96	4.62
Units 1-4									
SSE	259	0	68	18.15	13.19	0	78	12.46	12.62
FOG-1	259	0	25	3.63	3.81	0	23	3.87	4.27
FOG-4	259	0	15	2.01	2.46	0	6	0.46	0.87
FOG-6	259	0	20	2.80	3.59	0	5	0.38	0.73
FOG-10	259	0	48	5.63	7.73	0	4	0.39	0.71
NPE-1	125	0	20	3.95	4.94	0	10	2.29	2.40
NPE-2	164	0	26	1.63	2.64	0	14	3.01	2.67
NPE-3	168	0	40	3.74	6.07	0	22	2.09	3.51
NSE	259	0	22	5.20	4.16	0	23	5.34	4.12

Units 1-3									
SSE	155	0	122	24.83	18.79	0	114	21.55	18.84
FOG-1	155	0	19	3.65	3.81	0	18	4.19	4.10
FOG-4	155	0	14	2.62	2.52	0	5	0.86	1.22
FOG-6	155	0	25	3.50	5.07	0	6	0.60	1.01
FOG-10	155	0	12	2.15	2.42	0	4	0.63	0.88
NPE-1	141	0	21	1.68	2.92	0	21	4.37	4.64
NPE-2	68	0	9	1.34	1.64	0	13	3.13	2.72
NPE-3	54	0	6	0.74	1.25	0	6	0.91	1.57
NSE	155	0	29	7.33	6.21	0	32	8.78	6.85
Units 1-2									
SSE	62	0	79	34.21	15.09	0	73	31.48	15.06
FOG-1	62	0	15	3.02	2.94	0	13	4.95	3.13
FOG-4	62	0	20	5.42	4.66	0	6	1.44	1.48
FOG-6	62	0	10	2.11	2.66	0	6	0.81	1.30
FOG-10	62	0	7	1.95	1.94	0	6	1.11	1.37
NPE-1	60	0	5	1.13	1.29	0	10	4.05	2.52
NPE-2	28	0	4	1.29	1.05	0	7	2.75	1.97
NPE-3	5	0	4	0.80	1.79	0	2	0.40	0.89
NSE	62	0	27	11.81	5.54	0	25	11.85	6.12

Appendix Table C-2. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances by turbine operation pattern during the fall period at Little Goose Dam, Snake River, 1991.

Units operating, entrance	N	Upstream Counts				Downstream Counts			
		Min	Max	Mean	SD	Min	Max	Mean	SD
Units 2-4									
SSE	88	0	333	84.90	57.46	0	106	41.65	18.63
FOG-1	88	0	27	6.74	4.88	0	8	1.73	1.73
FOG-4	88	0	19	4.68	3.67	0	11	2.97	2.39
FOG-6	88	0	15	2.67	2.99	0	12	2.27	2.10
FOG-10	88	0	13	3.07	3.20	0	8	1.58	1.67
NPE-1	80	0	26	4.33	6.14	0	22	7.72	5.58
NPE-2	35	0	35	5.94	6.80	0	28	10.23	7.02
NPE-3	61	0	79	22.77	12.45	0	22	7.44	4.52
NSE	88	0	53	19.33	12.35	0	93	36.89	20.51
Units 2-3									
SSE	208	0	335	79.14	56.63	0	124	34.66	23.75
FOG-1	208	0	41	4.87	6.32	0	13	1.48	2.16
FOG-4	208	0	24	4.25	4.49	0	11	2.04	2.35
FOG-6	208	0	17	3.26	3.62	0	8	1.33	1.48
FOG-10	208	0	17	2.90	3.78	0	10	1.34	1.67
NPE-1	142	0	22	3.46	4.32	0	31	6.70	5.97
NPE-2	120	0	53	10.41	10.77	0	29	9.53	6.90
NPE-3	154	0	149	21.34	25.67	0	71	6.39	8.66
NSE	208	0	56	9.83	9.60	0	68	21.35	13.47
Unit 2									
SSE	206	0	225	52.76	49.83	0	85	22.22	18.80
FOG-1	206	0	48	5.73	8.71	0	10	0.98	1.68
FOG-4	206	0	19	2.59	3.88	0	8	1.11	1.51
FOG-6	206	0	19	2.31	4.20	0	10	0.92	1.52
FOG-10	206	0	21	2.12	3.83	0	10	1.00	1.57
NPE-1	127	0	24	4.20	5.43	0	24	5.96	4.87
NPE-2	152	0	28	6.30	6.44	0	32	6.73	6.51
NPE-3	133	0	119	21.27	27.75	0	31	4.44	6.27
NSE	206	0	39	6.38	7.33	0	116	14.71	13.81

Appendix Table C-3. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances by turbine operation pattern during the spring/summer period at Lower Granite Dam, Snake River, 1991.

Units operating, entrance	N	Upstream Counts Min	Max	Mean	SD	Downstream Counts Min	Max	Mean	SD
Units 1-6									
SSE	320	0	35	7.08	6.41	0	24	4.98	4.33
FOG-1	320	0	11	1.37	1.93	0	8	0.91	1.41
FOG-4	320	0	56	1.94	4.47	0	5	0.54	0.98
FOG-7	320	0	15	1.62	2.48	0	6	0.36	0.71
FOG-10	320	0	27	4.70	5.12	0	8	0.86	1.24
NPE-1	229	0	21	2.46	3.40	0	11	2.27	2.36
NPE-2	208	0	37	4.61	5.87	0	19	3.37	3.32
NPE-3	203	0	15	2.08	3.09	0	15	1.34	2.22
NSE	320	0	68	15.72	12.63	0	35	9.98	6.95
Units 1-5									
SSE	203	0	39	7.18	7.48	0	62	6.77	10.62
FOG-1	210	0	24	2.05	3.32	0	11	1.08	2.09
FOG-4	210	0	20	2.35	3.95	0	20	1.36	3.04
FOG-7	210	0	34	3.71	5.94	0	6	0.44	1.02
FOG-10	210	0	38	3.77	6.04	0	6	0.50	0.91
NPE-1	148	0	11	1.62	2.08	0	27	2.99	4.06
NPE-2	141	0	33	3.28	4.21	0	19	3.45	3.63
NPE-3	97	0	18	2.27	3.65	0	16	1.73	2.80
NSE	210	0	107	16.89	19.71	0	116	13.86	17.78
Units 1-4									
SSE	303	0	67	10.78	10.08	0	105	14.60	16.10
FOG-1	338	0	17	2.25	2.98	0	16	1.92	3.20
FOG-4	338	0	53	3.74	6.06	0	30	2.34	3.87
FOG-7	338	0	59	7.12	10.13	0	20	0.88	1.97
FOG-10	338	0	76	7.49	12.70	0	16	1.28	2.14
NPE-1	241	0	27	2.06	3.16	0	22	4.03	3.78
NPE-2	176	0	45	5.49	6.36	0	38	10.20	8.40
NPE-3	89	0	15	1.71	3.64	0	17	1.26	2.70
NSE	337	0	184	31.45	36.06	0	94	23.06	21.37

Units 1-3									
SSE	163	0	25	6.29	5.57	0	70	16.31	15.56
FOG-1	188	0	14	2.43	2.95	0	45	7.49	9.13
FOG-4	188	0	42	5.25	6.50	0	16	2.33	2.83
FOG-7	188	0	21	3.35	3.76	0	16	1.02	1.78
FOG-10	188	0	11	1.75	2.12	0	11	1.21	1.72
NPE-1	118	0	19	1.15	2.66	0	19	3.29	3.10
NPE-2	162	0	19	1.15	2.56	0	14	4.01	2.81
NPE-3	33	0	8	0.70	1.96	0	9	1.36	2.74
NSE	188	0	201	29.41	30.24	0	123	10.40	12.35

Appendix Table C-4. Minimum, maximum, mean, and standard deviation values for total hourly upstream and downstream counts at fishway entrances by turbine operation pattern during the fall period at Lower Granite Dam, Snake River, 1991.

Units operating, entrance	N	Upstream Counts Min	Max	Mean	SD	Downstream Counts Min	Max	Mean	SD
Units 1-3									
SSE	156	0	71	21.54	12.72	0	94	24.49	19.11
FOG-1	156	0	27	5.28	5.61	0	8	1.53	1.55
FOG-4	156	0	53	17.03	11.41	0	20	3.90	3.37
FOG-7	156	0	25	7.35	5.31	0	10	1.56	1.64
FOG-10	156	0	40	5.69	7.89	0	25	2.15	3.90
NPE-1	122	0	21	3.46	4.60	0	31	7.93	5.48
NPE-2	102	0	24	4.31	5.45	0	32	10.82	8.70
NPE-3	88	0	49	17.48	11.23	0	39	7.07	8.35
NSE	156	0	177	47.44	34.35	0	170	30.55	21.72
Units 1-2									
SSE	286	0	114	23.16	22.02	0	65	9.68	9.02
FOG-1	286	0	50	5.07	7.79	0	13	1.47	2.34
FOG-4	286	0	126	11.16	16.52	0	20	2.23	3.69
FOG-7	286	0	18	2.89	4.09	0	7	1.11	1.52
FOG-10	286	0	30	2.65	4.75	0	24	1.05	2.72
NPE-1	174	0	153	3.43	12.69	0	50	7.11	8.20
NPE-2	218	0	64	6.28	7.42	0	32	7.53	6.51
NPE-3	180	0	74	13.86	15.79	0	47	4.27	8.00
NSE	286	0	132	25.31	24.73	0	126	22.13	27.90
Unit 1									
SSE	138	0	363	34.78	44.52	0	135	13.11	17.78
FOG-1	138	0	20	2.49	4.69	0	9	1.06	1.69
FOG-4	138	0	47	4.60	7.54	0	15	2.26	3.36
FOG-7	138	0	13	1.46	2.93	0	5	0.92	1.26
FOG-10	137	0	43	2.82	5.85	0	33	1.35	4.16
NPE-1	89	0	22	1.89	4.32	0	28	5.51	5.54
NPE-2	70	0	38	10.39	9.17	0	62	11.21	12.87
NPE-3	117	0	64	10.38	12.89	0	42	3.94	9.28
NSE	138	0	96	22.43	22.56	0	152	19.84	23.63